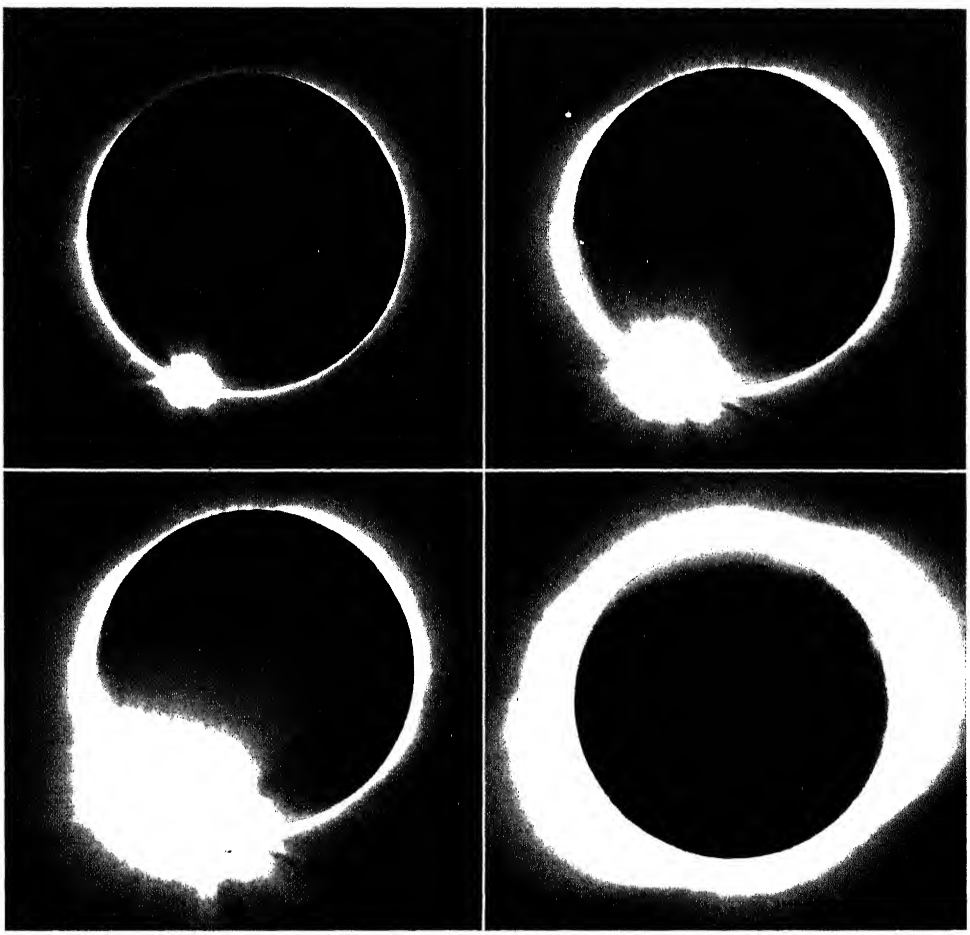
Resonance

February 1996 Volume 1 Number 2

journal of science education



Life: Complexity and Diversity ❖ Randomness and Probability ❖ Isomers of Benzene ❖ Artificial Neural Networks ❖ Bose-Einstein Condensation

Resonance is a monthly journal of science education published by Indian Academy of Sciences, Bangalore, India.

Editorial Office: Indian Academy of Sciences, C V Raman Avenue, PB No. 8005, Bangalore 560 080, India.
Tel:+91 (80) 3342310 / 3342456, Fax:+91 (80) 3346094, email:resonanc@ias.ernet.in

Editorial

N Mukunda, Chief Editor

The inaugural issue of ***Resonance*** was released by Professor U R Rao, General President of the 1996 Session of the Indian Science Congress held at Patiala, at a special function arranged on 4th January, 1996.

Now that our first issue has seen the light of day, it is appropriate to say a little bit about all those who have helped make ***Resonance*** a reality. The task of conceiving and giving shape to the myriad production aspects involved in such a venture was handled by production editor Srinivas Bhogle and his associate A S Rajasekar, from the National Aerospace Laboratories, Bangalore. The logo for ***Resonance*** — deceptively simple in appearance and yet so evocative — was created by P N Shankar. For logos of individual departments, we turned to Ayan Guha, a student in the Department of Physics at the Indian Institute of Science, Bangalore. Gentle humour and talent form such a fine combination.

Do write to tell us what you would like to see in future issues of *Resonance*. The quality of the initial effort, and the support we hope to get from our readers and future contributors, encourages us to believe that we will succeed.

The assistant editors have tried to achieve as reasonable a level of uniformity in style and presentation as was practicable, given the spread of subjects and contributors. As for the latter, our sincere thanks to them for responding so readily with their contributions.

We hope that our readers have felt that the inaugural issue of ***Resonance*** showed imagination, good taste and quality in both appearance and content. New departments — letters, correspondence, guest columns, reflections,..., will gradually be added. Do write to tell us what you would like to see in future issues of the journal. And to those of you who have a flair for writing for the young, here is a request — pick up your pens or your PC's and write; you will feel and may even look younger after the effort!

After the Eclipse

The cover of this issue shows pictures of the total solar eclipse which was visible in northern India on October 24th, 1995. Much has been written about the eclipse in newspapers and magazines, bringing out the awe-inspiring natural beauty of the phenomenon. But it is also of real scientific benefit to astronomers who study the sun. Can one not get the same results even at other times, by blocking the direct rays from the sun with a suitable disc placed in the telescope? No! While one can block the direct rays from the sun, there are rays which arrive from other directions because of scattering in the atmosphere or in the instrument. If one looks in a direction away from the sun, one sees the blue light of the daytime sky, which is nothing but scattered sunlight. The intensity is only about one millionth of what one sees when looking directly at the sun. But the corona of the sun (the glowing region surrounding the moon in the pictures of the eclipse) is even fainter than this! It cannot be seen from the earth under normal (non-eclipse) conditions. During a total solar eclipse, however, the atmosphere for nearly a hundred kilometres around the observer receives no sunlight. The sky is practically like that at night, and the faint outer layers of the sun are, all too briefly, available for study. This situation may be compared to the driver of a car being glared by the headlights of an oncoming vehicle. She can block the direct rays by placing a hand in the way. But if the glass of the windscreen is scratched or dusty, it appears bright due to scattered light. It is then difficult to make out dim objects on the road. The eclipse corresponds to the (rare!) situation when the driver of the oncoming vehicle turns off its headlight, and the whole windscreen is in darkness.

The chemical element helium was first detected during an eclipse in a spectrum of the sun's outer layers taken in the nineteenth century by English astronomers. The site was in the tobacco fields of Guntur, in Andhra Pradesh. Even though eclipse studies have been carried out for a long time, instruments become more sophisticated and more portable with each passing year. Further, the sun changes in its properties over a cycle of roughly eleven years, during which the number of sunspots, the magnetic field, and other properties vary. Therefore, eclipse studies still have their role in solar astronomy, even in an age of space instrumentation. The cost of an eclipse expedition is still far less than that of a high altitude observatory or a space mission.

One marvellous use of eclipses is in dating historical events. A solar eclipse is visible from a given point on earth only once every five hundred years or so. When Babylonian astronomers observed an eclipse, they recorded the precise date- in their calendar! The conversion to our calendar is not known accurately. But it is enough to know it with an error of less than a few hundred years. One can then work out which solar eclipse was seen by them, and thereby obtain the conversion to the exact day. One fascinating byproduct of this calculation is that while the sun, moon and earth were

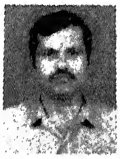
aligned on that day, it appears that Babylon was on the night side of the earth! The fact that the eclipse was indeed visible from Babylon means that something had gone wrong with the calculation. The total angle turned by the earth in about three thousand years had been underestimated by a hundred degrees, leading to an error of several hours in the predicted time. Astronomers believe that the discrepancy is because the earth has not been rotating at a fixed rate. It was spinning slightly faster in the past, and the day was a few hundredths of a second shorter a few thousand years ago than it is now.

Other studies during an eclipse have been made in the atmospheric and biological sciences. The removal of solar heating can cause some interesting effects in the atmosphere. So much of life is tuned to the regular cycles of light and darkness that it can be influenced in strange ways by the abnormal pattern. The general question one can ask about any study carried out during an eclipse is whether it could have been done more simply even without an eclipse, i.e. when the sun sets. Some of the results claimed and even reported in the press come under this category! Results obtained from a location where the eclipse was partial are open to a similar criticism. Such experiments do not exploit the unique circumstances which prevail during a total solar eclipse.

The total eclipse is possible because the angular size of both the moon and the sun are nearly the same, about half a degree. This matching is quite accurate. In fact, when the moon is at the furthest point of its elliptic orbit around the earth, its angular size can become slightly smaller than that of the sun. If there is an eclipse at this position, the moon is unable to cover the sun fully, causing the rare 'annular eclipse' in which a bright ring of sunlight peeps out all around the moon.

There is no physical or astronomical principle which requires these two angular sizes to be so nearly equal. We should regard it as an astronomical accident that we are able to enjoy this spectacle. And we should enjoy it while we can!. According to astronomers, the spinning earth is gradually being twisted backwards, i.e. its rotation is being 'braked' by the friction of the two tidal bulges raised in the oceans by the moon. Newton's law of action and reaction then tells us that the moon must be pushed forward in its orbit. It will therefore gradually recede from the earth. A billion years from now, there may be no total eclipses to gape at. And a hundred million years ago, the dinosaurs enjoyed slightly longer eclipses than we do today!

Rajaram Nityananda

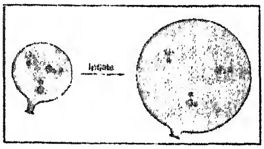


The eclipse photographs which appear on the cover page were taken by Mr Dilip Kumar, a member of the Association of Bangalore Amateur Astronomers. It may be noted that he ground and polished a special mirror just to take these photos. Mr Dilip Kumar, who holds a diploma in electrical engineering works in the Inspection Department of ITI, Bangalore. His hobbies are astronomy and photography.

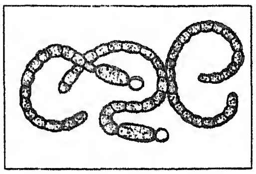
Resonance journal of science education

February 1996 Volume 1 Number 2

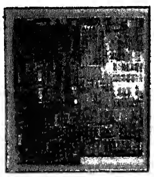
12



18

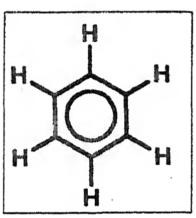


32



74

90



GUEST ARTICLE

SERIES ARTICLES

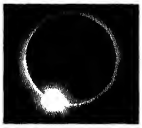
The Series Articles on Algorithms *by R K Shyamasundar,* Fascinating Organic Transformations: Rational Mechanistic Analysis *by Subramania Ranganathan and* Know Your Chromosomes *by Vani Brahmachari will appear in the next issue.*

GENERAL ARTICLES

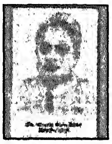
FEATURE ARTICLES

102 RESEARCH NEWS

115 BOOK REVIEWS



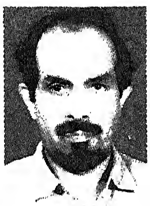
Front Cover
Photographs of the total solar eclipse which was visible in northern India on 24 October 1995.



Back Cover
Satyendra Nath Bose (1894-1974).

Higher Education in India

R Narasimha



There is nothing so practical as a good theory, said the great Boltzmann. In our country, it seems to me, we still have no theory of education; we have muddled along for the last 40 years, with assembly, court and Parliament laying down various decrees, often of extraordinary import, and academics usually complaining helplessly about the deplorable state of education in our schools and universities.

To understand why this has happened, we must begin by realizing that education has not only professional objectives, but social and cultural ones as well. Let me explain. There is first of all the need to make good citizens, for without a society that is viable (and a nation that is strong and confident) the other objectives cannot in any case be met. A lack of recognition of this aspect of education widens the gulf between legislator and educator — the former is continually putting out fires ignited by an inflammable system, and the latter is bewildered and frustrated by constant political interference. The professional objectives, which academics are happier discussing — often at great length — must among other things offer inspiration for the creative few, and a satisfying means of livelihood to a large number of others. On the latter point, recall what Gandhiji once said, to the effect that even God dare not appear before a hungry man except in the form of bread; similarly, an educational system cannot afford to ignore the demand for suitable employment by young men and women. Finally education enhances our appreciation of the world around us, the history and the arts that people have created, and the scientific understanding of nature that we have gained over the centuries. Such cultural objectives need particular attention, especially because they lead to benefits that may not be immediately tangible and may on the other hand be easily destroyed.

Gandhiji once said something to the effect that even God dare not appear before a hungry man except in the form of bread; similarly, an educational system cannot afford to ignore the demand for suitable employment by young men and women.

A good educational system must meet all these objectives. Is it possible to create such a system? I believe so, for, although no country in the world seems entirely happy with the system it has, we must admit that many have systems more satisfactory than our own. The question therefore is: how can we proceed to improve our system?

A first interesting point is that there is great diversity in the educational systems that different countries have devised for themselves. Thus, at Cambridge you can get a B.A. in "natural sciences" or engineering three years after entry (with three short but intense terms of 8-10 weeks each during the year). In Germany, on the other hand, you need 5 years before you get the first "Diplom" in engineering. In the US you take a 4-year course for a Bachelor's degree in science or engineering, but you need to spend *at least four more* if you wish to practise medicine. In many European countries the state goes to great trouble to ensure uniform standards, at entry to the university as well as at graduation, whereas the US system allows for considerable variation — the interested public soon finds out for itself which element of the system delivers what. In spite of this loose regulation in the US, however, it is universally recognised that their (post-) graduate educational system is about the best available anywhere.

What does this tell us? I think the chief conclusion to be drawn is that, while certain professional standards must of course be met by any national system, there is a lot of room for variation, i.e., for tailoring the system to the social and cultural needs of each country. During the last two centuries, Europe and its educational system have often been driven by imperial ambition (the motto of Imperial College stands for Science as Shield of Empire), and our own (with its extraordinary emphasis on English, geography and such other subjects in school) by the British need to manufacture clerks and other functionaries to run their Indian empire. If we sweep aside these colonial cobwebs, what kind of system would we need to devise for ourselves?

There is great diversity in the educational systems that different countries have devised for themselves. This suggests that there is a lot of room for tailoring the Indian system to the social and cultural needs of the country.

If we agree that our educational system should meet our cultural and social needs, we should begin by examining the peculiar aspects of the Indian scene. The most important of these are, in my view, an extraordinary cultural diversity, a social stratification that has deep historical roots and has left the vast majority of our citizens disadvantaged in many ways, and a strong and ancient tradition of formal learning among a minority of the population. There is not enough space to argue in detail in this column precisely how these factors should influence the design of our system, but let me state conclusions that appear obvious to me.

- *Do not attempt a uniform system all across the country.* In a society where the ideal (as defined by Gandhiji again) has often been that each man should be left free to design his own religion, can we succeed in making an effective educational system that is uniform? The US has already shown us how a diverse system can be managed quite effectively.

- *Declare that every citizen who meets certain minimum entry level qualifications has the right to university education.* If (as already pointed out) the vast majority of our people feel that for centuries they have been disadvantaged — socially, culturally and economically — and many of them see education as a social passport, I think their feeling is entirely legitimate, and should be *encouraged* (incidentally taking the opportunity to produce good and productive citizens for the republic: that is the task of the political and educational leadership). However, this problem is now being tackled by a cumbersome system of reservations and quotas, decreed by the politicians and judges of the land; educationists have no voice, because (I am sorry to say) we have refused to analyse it as *our* problem.

The peculiar aspects of the Indian scene are an extraordinary cultural diversity, a social stratification that has deep historical roots and has left the vast majority of our citizens disadvantaged in many ways, and a strong and ancient tradition of formal learning among a minority of the population.

Indeed, our educational scene today is resonant with a culture of poverty and scarcity: it has what may be called a ration-card mentality, and reminds me of the situation in the country regarding food till the seventies. (Those old enough to have lived through those times will recall how uncertain the availability of

food was: the prudent and well-off hoarded grain and kept access lines to their rural sources open — just as they now save money and keep educational lines to the US open — while government made elaborate rules for *equitable* distribution, promptly circumvented by an ingenious public.) Fortunately the green revolution changed all that: although not everybody is still well-fed, far fewer people starve or hoard grain, and you can buy rice at either a few rupees a kilo or a hundred, depending on what you need or can afford. A similar revolution has to occur in education, with a wide variety of courses designed to suit different aptitudes, abilities, cultures etc. I cannot understand, for example, why there are not a large number of three-, or even two-, year degree courses whose objectives would be to : (i) prepare each student for suitable employment, (ii) make her or him a good Indian citizen, and (iii) enhance her or his appreciation of cultural pursuits, from her or his own or other parts of the country (or world), in such fields as languages, literature, philosophy, music, dancing etc. (not excluding science!). This could be a good pattern for an Indian-style liberal/vocational education, which may appear to be a contradiction in terms in the West but will suit our cultural traditions very well for even the disadvantaged Indian often has hidden cultural strengths that this counterparts elsewhere in the world generally lack; but our educational system does not appreciate this, because (I believe) the ghost of Macauley, with his grotesque contempt for all forms of Indian learning, still haunts our academic corridors. Of course such initiatives will require money, but there is no alternative but to find it; after all we now spend only a little more than 3% of our GNP on education, and doubling it would not at all be too much to ask or do, and would only put us roughly on par with other societies. My friend Prof K Krishna Prasad has recently computed that, even after taking purchase power parity into account, the Netherlands spends ten times more in real money per pupil than India does.

The Prescription

- Do not attempt a uniform system all across the country.
- Declare that every citizen who meets certain minimum entry level qualifications has the right to university education.
- Make the system flexible.

A revolution similar to the Green Revolution has to occur in Indian education, with a wide variety of courses designed to suit different aptitudes, abilities and cultures.

The point I am making is that while academics tend to view equity and excellence as conflicting objectives (defining the latter rather too narrowly), and specific institutions may strike their own

The ghost of Macauley, with his grotesque contempt for all forms of Indian learning, still haunts our academic corridors.

balance between the two, there is no question that the national system must provide for both; furthermore I believe it can actually be done quite well, provided we suit the system to our cultural ethos.

- *Make the system flexible.* We must now have one of the most absurdly rigid educational systems in the world. At every stage in one's educational career, doors are being shut, rather than opened; you choose this option, you can't become a doctor; you choose another, you can't study mathematics; you choose a third, you can never become a historian. Why? We can cite any number of the most distinguished and creative minds in the world who started out to learn something, but found that what they wanted was rather different. The prospectus of Cambridge University tells potential applicants for admission: "You can arrive in Cambridge expecting to become a physicist or zoologist, and emerge after three years as a metallurgist or a psychologist". Unfortunately, this cannot happen even in the best universities or institutes in India today. Why? We cannot blame the politicians for this rigidity; it is there because we teachers want it. It is almost as if we have a passion for stamping people in India: at every stage in one's life, beginning with birth, and going through school, college etc., society is stamping one's 'passport' and putting its *gurtu* on it, and telling us what we *can't* do later on. Can we not liberate ourselves from this system?

We have a passion for stamping people in India: at every stage in one's life, beginning with birth, and going through school, college etc., society is stamping one's 'passport' and putting its *gurtu* on it, and telling us what we *can't* do later on.

All of us know students whom we considered mediocre in India, but who blossomed into confident, productive, and sometimes distinguished personalities in the US. If so many students hanker after going to the US, one reason is of course the promise of a green card and eventual prosperity, but another very strong one I believe is the sense of liberation they feel once they are out of the clutches of the Indian system.

Now education in science, which is the major concern of this journal, will also (I believe) have to take into account the kind of

factors mentioned above. On the one hand it must nurture that small number of precious and extraordinary people who, in their pursuit of truth and beauty will create the new science that will be part of our culture (or even commerce) in later years; on the other hand, the system must also enable the vast majority of others to secure a decent and satisfying career in the ever-changing world of modern technology. As the bigger social and cultural problems associated with education in general get tackled effectively, we will be in a far better position to devise a more satisfactory system for science as well, recognizing that science is understanding, but that it is also power.

A very strong reason why so many students hanker after going to the US is the sense of liberation they feel once they are out of the clutches of the Indian system.

In fact the Academy Paper on the subject (*Current Science*, 1995, 68:255-267) already offers many excellent suggestions (including a three-stream Bachelor's programme in science), and a specific course of action. It is time that scientists (and other academics) start reexamining the fundamental basis of our educational system (not hesitating to look at radical alternatives), and so regain a sense of control on what they teach to whom, and how.

Address for correspondence
R Narasimha
Indian Institute of Science/
Jawaharlal Nehru Centre for
Advanced Scientific
Research,
Bangalore 560 012, India.

EH? YOUR PH.D.? WELL ... I'VE GOT TO LOOK AT YOUR GUIDE'S PALM FOR THAT!

MOHAN DEVADAS

Origin (?) of the Universe

2. The Expanding Universe

Jayant V Narlikar

Jayant Narlikar, Director, Inter-University Centre for Astronomy and Astrophysics, works on action at a distance in physics, new theories of gravitation and new models of the universe. He has made strong efforts to promote teaching and research in astronomy in the universities and also writes extensively in English and Marathi for a wider audience on science and other topics.

This six-part series will cover: 1. Historical Background. 2. The Expanding Universe. 3. The Big Bang. 4. The First Three Minutes. 5. Observational Cosmology and 6. Present Challenges in Cosmology.

The expansion of the universe was established based on observations made in the 1920's, of the Doppler shift of light from galaxies. The proportionality between velocity and distance is the famous Hubble Law. Simplified mathematical models of the universe are based on the idea, which is supported by observations, that there are no preferred locations or directions in space.

Hubble's Law

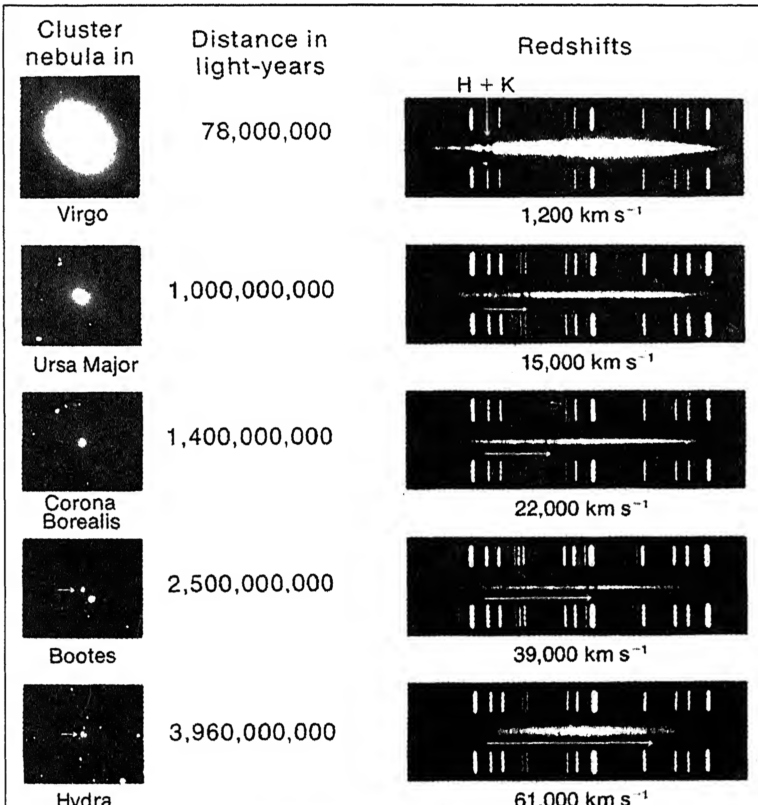
By the beginning of the present century, astronomers had two important sources of information. Photographic plates more efficient than the human eye supplied images of faint objects while spectrographs analysed the light forming these images into components of different wavelengths. Before proceeding to Hubble's Law let us note how these two sources of information helped early extragalactic astronomy.

The spectra of nebulae were first investigated in 1864 by William Huggins by visual inspection. Only the continuous distribution was clearly visible; the lines, if any, were too faint to be detected. The brightest of the nebulae, M31, was subsequently investigated in detail. (M31 is the catalogue number of the galaxy in the compilation made by Charles Messier). In 1899, J Scheiner established the presence of absorption lines in the spectrum of M31, although he was unable to measure their precise wavelengths.

The breakthrough was made in 1912 by V M Slipher at Lowell Observatory, using a fast camera attached to the observatory's 24-inch refracting telescope. When Slipher measured the wave-

lengths of the absorption lines in M31, he found a somewhat unexpected result. The spectral lines appeared to be displaced from their natural locations, their observed wavelengths being systematically shorter than the expected (signature) values. The shift was thus towards the violet end of the spectrum. M31 was however the odd one in a steadily growing list of nebulae studied by Slipher, for, by 1925, Slipher's list of such shifts of absorption lines in the spectra of nebulae like M31 had grown to forty one, and it had become clear that the general rule was of a shift in the opposite direction, towards the red end of the spectrum. Such a *redshift* may be defined quantitatively as the fractional increase in the original wavelength.

The spectra of nebulae were first investigated in 1864 by William Huggins by visual inspection. Only the continuous distribution was clearly visible; the lines, if any, were too faint to be detected.



Red-shifts are expressed as velocities, $c\, d\lambda/\lambda$. Arrows indicate shift for calcium lines H and K. One light-year equals about 9.5 trillion kilometers, or 9.5×10^{12} kilometers.
Distances are based on an expansion rate of 50 km/sec per million parsecs.

Figure 1 Redshift-Faintness Relation: Hubble's observations demonstrate how (as we go down the figure) for fainter and fainter galaxies (shown on the left), the shift of absorption lines in the spectra (shown on the right) increases. Hubble converted faintness into distance of the galaxy, and spectral shift into its radial velocity, to arrive at a velocity distance relation.

Physicists already had an explanation for such spectral shifts. First discovered by the Dutch physicist C Doppler (1803-54) in the case of sound waves, the explanation is equally applicable to light waves. The shifts are expected to occur whenever there is a relative motion between the source and the observer. If the relative motion is one of recession, a redshift is observed: if it is of approach, there will be a violetshift. The magnitude of the red-shift can be used to calculate the speed of recession of the source. Edwin Hubble and his young colleague Milton Humason carefully analysed the data on spectral shifts. In particular, before deciding whether a distant nebula was approaching or receding from our galaxy, they corrected for our own motion relative to the galactic centre (recall that the earth moves around the sun, which in turn moves around the galactic centre).

Looking at his distance estimates, Hubble noticed a definite pattern: the greater the distance, the larger the redshift, and hence greater the speed of recession of the nebula. In 1929 Hubble expressed this pattern as a velocity-distance relation.

Meanwhile, using other tools of imaging, astronomers had made enough progress to be able to make estimates of the distances of many of these faint nebulae. Using an (admittedly crude) assumption that a fainter object is farther away, they thus had a first glimpse of the size of the extragalactic universe. Looking at these distance estimates, Hubble noticed a definite pattern, namely, the greater the distance, the larger the redshift, implying therefore a greater speed of recession of the nebula. Hubble in 1929 expressed this pattern as a velocity-distance relation:

$$V = H \times r$$

where V is the velocity of a nebula and r its distance. The constant of proportionality, H, in the above relation is called *Hubble's constant*, and the relation *Hubble's law*.

It is clear from the above relation that $1/H$ has the dimension of time. Hubble's own estimate of $1/H$, of about 1.8 billion years, turned out to be a gross underestimate, largely because the nebular distance estimates of the 1920's contained several large systematic errors. The present estimates of $1/H$ are in the range of 10 to 15 billion years.

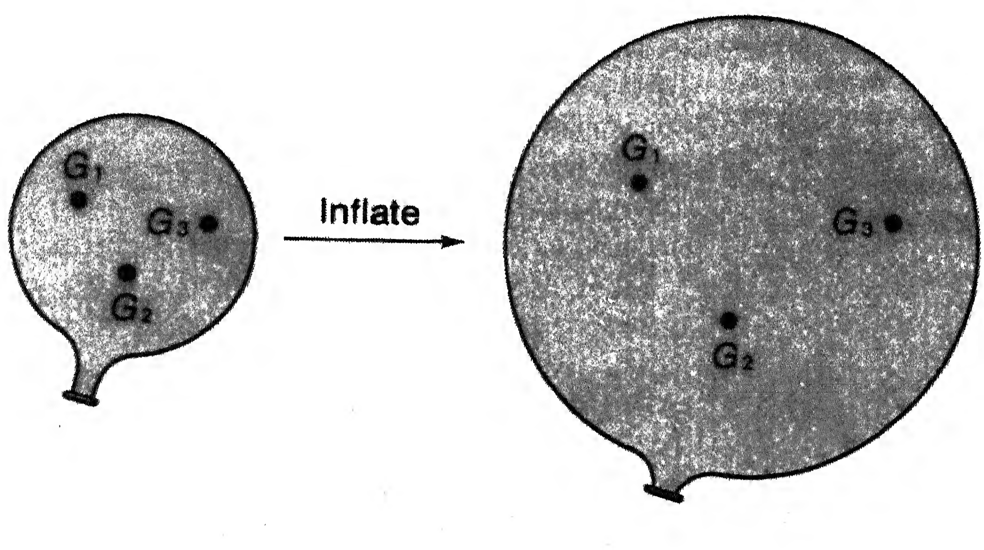
The Expanding Universe

The velocity-distance relation which Hubble obtained originally from observations of eighteen nebulae has since been determined for a much larger number of galaxies out to distances more than several hundred times greater than those in his original sample. The phenomenon of the redshift and its relationship to distance appears to hold. So we have *prima facie* evidence that other galaxies appear to be rushing away from our own. Have we finally arrived, then, at a situation which singles out our location in the universe as a somewhat special one?

No. A little reflection on the velocity-distance relation will assure us that there is nothing special about our location. Observers viewing the galactic population from another galaxy will find the same law as Hubble, with all galaxies rushing away from their own.

The expanding universe exhibits two important properties: there are no privileged positions and no preferred directions.

Figure 2 The Expanding Universe: An anology explaining this phenomenon is that of a balloon with dots G_1, G_2 ... on it. As the balloon is blown up the dots move away from one another. Each dot may 'think' that the others are receding from it.



As we inflate the balloon, the dots G_1, G_2, and G_3 on its surface move away from each other. Yet, no dot can claim a privileged site on the spherical surface.

Weyl's postulate assumes that the large scale motion of typical units, the galaxies, is highly streamlined. This serves as a reasonable first approximation.

To appreciate this remark, imagine the universe as a lattice structure, with galaxies occupying the lattice points. Suppose now that the entire lattice expands. All points of the lattice will therefore move away from one another, with no particular point occupying a preferred position. This analogy helps us to visualize the oft-repeated statement that the universe is expanding.

The expanding universe exhibits two important properties: there is no privileged position, as we just mentioned, and no preferred direction. Observers brought blindfolded to any location cannot, on removing their blindfolds, tell where they are or in what direction they are looking! Perfect democracy prevails in this universe. This is the kind of symmetry that Aristotle would have liked! But how does his modern counterpart in theoretical cosmology deal with the question of modelling the universe?

Mathematical Models: Basic Assumptions

The concept of an expanding universe can be quantified by using two simplifying assumptions. The first is the so called *Weyl postulate* which assumes that the large scale motion of typical units, the galaxies, is highly streamlined. Thus, there is no randomness, no collisions in the way galaxies are supposed to

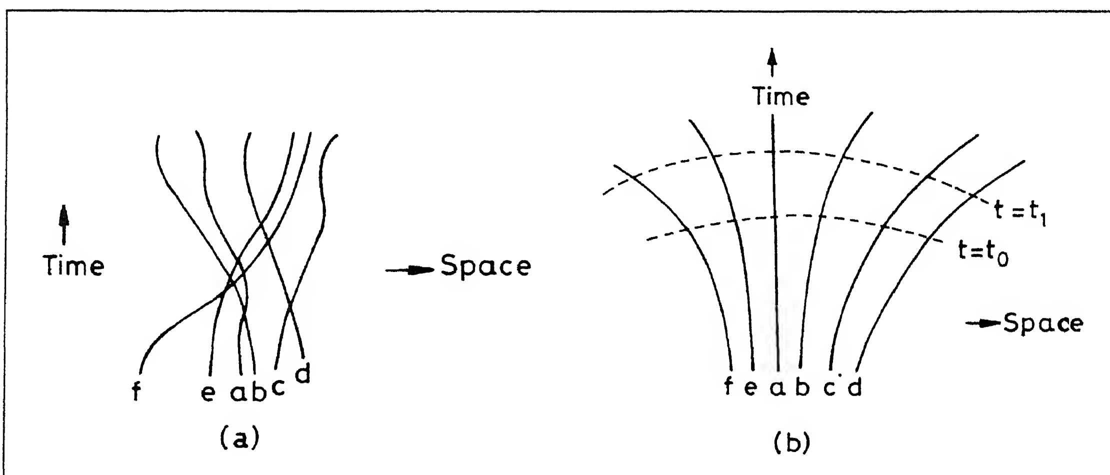


***Figure 3** The Weyl Postulate : A streamlined motion of galaxies shown in (b) may be contrasted with chaotic motion in (a). The former permits us to identify a cosmic time coordinate t. In (b) the streamlines of motion cut orthogonally across surfaces of constant cosmic time.*

we will see later, this idealized situation does not represent the real universe but serves as a reasonable ›ximation.

. postulate enables us to identify a unique time coordi- ›e *entire* universe. Just as in a wide column of soldiers in strict order, we can identify soldiers in the same row, identify galaxies at the same cosmic epoch. This time '*t*' he cosmic time.

d assumption, known as the *cosmological principle*, states etry referred to earlier. In scientific jargon we say that n cosmic time the universe is *homogeneous* and *isotropic*, ans that all locations in the universe have physically roperties, and the universe looks the same in all direc- n viewed from any location.

t part of this series we will investigate the models that on these simplifying assumptions.

Suggested reading

H Bondi. Cosmology. Cambridge University. 1960.

J V Narlikar. The Lighter Side of Gravity. W H Freeman and Co. 1982.

F Hoyle. Astronomy and Cosmology - A Modern Course. W H Freeman and Co. 1975.

Address for correspondence
Jayant V Narlikar
IUCAA, PB No. 4,
Ganeshkhind,
Pune 411 007, India

Pablo Picasso said ... "So how do you go about teaching something new? By mixing what they know with what they do not know. Then, when they see in their fog something they recognise, they think 'Ah, I know that!'. And then it is just one more step to 'Ah, I know the whole thing!' And their mind thrusts forward into the unknown and they begin to recognise what they did not know before and they increase their powers of understanding".

S E Luria observes ... (in *A Slot Machine, A Broken Test Tube, An Autobiography*): "The image of the impartial scientist uncommittedly weighing the various alternatives is a gross simplification. Scientists, like everyone else, have opinions and preferences in their work as in their lives. These preferences must not influence the interpretation of data, but they are definitely an influence on their choice of approaches.

Life: Complexity and Diversity

2. The Expanding Biosphere

Madhav Gadgil

Madhav Gadgil is with the Centre for Ecological Sciences, Indian Institute of Science and Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore. His fascination for the diversity of life has prompted him to study a whole range of life forms from paper wasps to anchovies, mynas to elephants, goldenrods to bamboos.

Early life on earth arose in an environment without oxygen. In an atmosphere with increasing oxygen concentrations, co-operation among teams of biomolecules led to the emergence of multicellular organisms which over time evolved to give rise to higher plants and animals.

Early Life

Life expands continuously. It constantly draws in non-living matter and energy and converts them into living matter. Living creatures produce more and more living creatures like themselves. The efficacy with which any living creature accomplishes these two tasks depends on how good its team of proteins, nucleic acids and lipids is at making more copies of itself and of other associated molecules (*Figure 1*). The key to the quality of this performance lies in the efficacy of the instructions resident in the nucleic acids,for assembling proteins and in turn a whole range of other molecules. These instructions are passed largely intact from a cell to its daughter cells, from one living creature to its offspring.

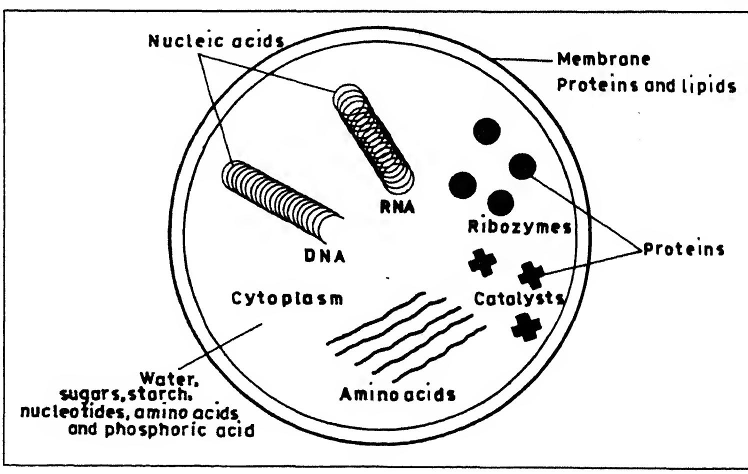


Figure 1 Living organisms are basically teams of mutually co-operating molecules.

They thus constitute the hereditary material or the genetic constitution of an organism. The better an organism's hereditary abilities are tuned to its setting, the more effectively it converts non-living matter into more copies of its own self. This sets up a game in which organisms get ever better at adapting to and populating the world. This is what Darwin termed "survival of the fittest". This process of natural selection has produced an ever greater number of organisms fitted to increasingly diverse environments for life.

Organisms need resources of matter and energy to keep their molecular teams in good repair, and to replicate them. Three and a half billion years ago life probably originated in shallow warm seas out of a soup of organic molecules that had been produced through the action of a variety of non-biological agents on the early earth. As we have seen in the previous article (*Resonance*, 1(1)), a few hundreds of simple building blocks make up the tremendous variety of living organisms on the earth today. Essentially the same form of basic instructions set down in the nucleic acids orchestrate the functions of all the diverse forms of life. This strongly suggests that all life had a single, common origin. It is very likely that in the beginning there was just one simple kind of living organism. It lived in the soup of organic molecules in the warm, shallow primeval seas, making up the world's earliest ecosystem and using the simple organic molecules in its environment as raw materials to repair and replicate itself. The chemical bonds between carbon, hydrogen, oxygen, nitrogen and phosphorus in these molecules supplied the energy to sustain this activity. There was essentially no free oxygen in this early world. This presumed early life may then be visualized as resembling anaerobic bacteria living in the thick slurry of organic molecules in the bowels of a biogas plant.

It is very likely that in the beginning there was just one simple kind of living organism.

Over time, life has managed to invade almost every type of habitat on the earth, forever extending the limits of the biosphere. It is out in the open ocean and in the deepest trenches of the ocean floor. It is in little pools in the Antarctic ice cap and in the hot,

sulphurous springs on land. It has come out of the waters onto land, colonizing not only the warm moist niches, but thriving in the driest of deserts and on cold mountain tops. It has taken to air, as pollen grains of flowering plants and spiders with their little balloons; as flying lizards gliding from tree to tree and birds flying from the Arctic to the Antarctic. This of course has happened at a slow pace over billions of years in small steps, with living organisms progressing to habitats more and more different from their ancestral homes in the warm, shallow seas.

New Ways of Life

All living organisms must maintain a flux of energy or energy rich matter through their bodies.

Living organisms have also taken to new ways of tapping resources for, every organism must necessarily maintain a flow of energy and materials through its body to keep itself going. Thus green plants absorb the sun's rays and give out heat. Their roots take in water which is lost through the leaves. The roots absorb nitrogen, phosphorus, potassium and molybdenum, which are eventually returned to the earth with drying leaves and roots. Animals feed on other plants or animals, breathe in air and drink water. They excrete dung and urine and breathe out air. Without exception, all living organisms must thus maintain a flux of energy or energy rich matter through their bodies.

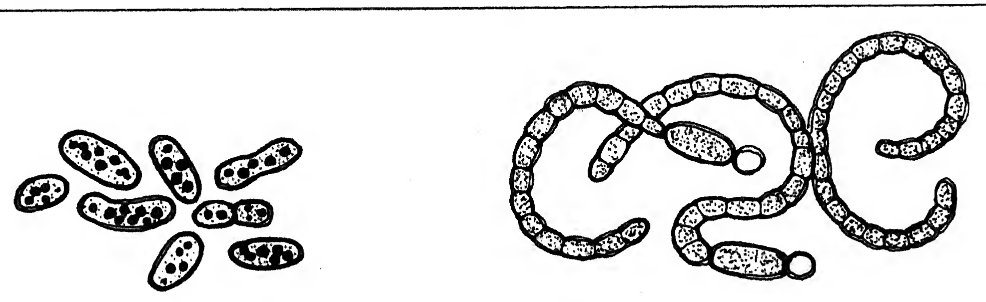
Living organisms have been elaborating increasingly complex ways of achieving this over their evolutionary history. The earliest organisms were born in an organic soup; so for them these organic molecules served at once as the source of matter and energy. They simply lapped up what had been formed through physical processes over the first billion years of the history of the earth. We still have certain bacteria and fungi that grow in rotting wood or in corpses of animals, which follow this route. These decomposers take in preformed organic molecules available for free in their surroundings. That was the only way in which life was practised for a very long time, perhaps for the first billion years. Over this period the supply of preformed energy rich organic molecules must have begun to run low. In any case, there came on

the scene, new organisms that began to exploit an entirely new source of energy - sunlight. Amongst the earliest to do so were sulphur bacteria which use the energy of sunlight to split hydrogen sulphide. The hydrogen atoms produced may then be combined with carbon dioxide to produce organic molecules that form the raw material for the fabrication of living organisms. The early environments of the earth were relatively rich in hydrogen sulphide discharged from the then active volcanoes. But a far richer source of hydrogen is dihydrogen oxide - water. Breaking the hydrogen-oxygen bonds in water however requires more energy. This feat was achieved by cyanobacteria or bluegreen algae that appear to be descendants of sulphur bacteria. With the help of special pigments they learnt to use more energy-rich sunlight of shorter wavelength, to produce simple organic molecules from the abundantly available molecules of water and carbon dioxide. In the process of making sugar from carbon dioxide and water, they produced oxygen, as do the green plants today (*Figure 2*).

The early organisms were adapted to exist in an oxygen-free environment.

For the next billion or more years of evolutionary history there existed on earth simple bluegreen algae and bacterial decomposers. But now the environment on earth was being radically transformed. In the beginning there was little free oxygen, either in the air, or dissolved in the water. The early organisms were in fact adapted to exist in an oxygen-free environment. Since oxygen is a highly reactive element, it rapidly combines with organic molecules. This is after all what happens when wood or a candle

***Figure 2** Sulphur bacteria use sunlight to split hydrogen sulphide ; cyanobacteria use it to split water to synthesize simple carbohydrates.*



$$2CO_2 + 2H_2S \xrightarrow{\text{Sunlight}} 2(CH_2O) + 2S + O_2$$

$$CO_2 + H_2O \longrightarrow (CH_2O) + O_2$$

burns. The machinery of early organisms could not, in fact, tolerate free oxygen. But this did not keep bluegreen algae (which are really bacteria) from splitting off oxygen from water molecules and combining hydrogen atoms with carbon dioxide to produce sugars. So the concentration of oxygen in air and water kept increasing. Living organisms had to somehow deal with this new situation.

The important ability of using oxygen to speed up living processes was the consequence of a new kind of mutualism. This was the formation of a single organism out of the merger of two different kinds of bacteria.

Quickening Pace

To protect their molecules from combining too rapidly with the oxygen in the environment, bluegreen algae evolved special structures and enzymes. But as oxygen concentrations increased another more attractive possibility was exploited; this was to use oxygen to speed up the flux of energy through the bodies of living organisms. This is what most organisms, including human beings, do today. We eat energy-rich food, breathe in oxygen, use the oxygen to release the energy trapped in food molecules, use this energy to maintain our machinery to grow and reproduce. But this ability to use oxygen to facilitate energy fluxes came only after a long history of a billion and a half years of evolution.

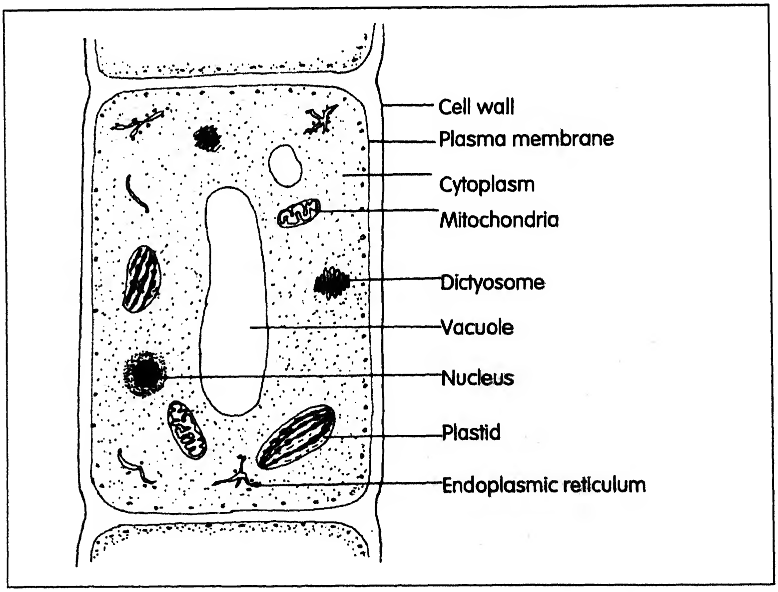
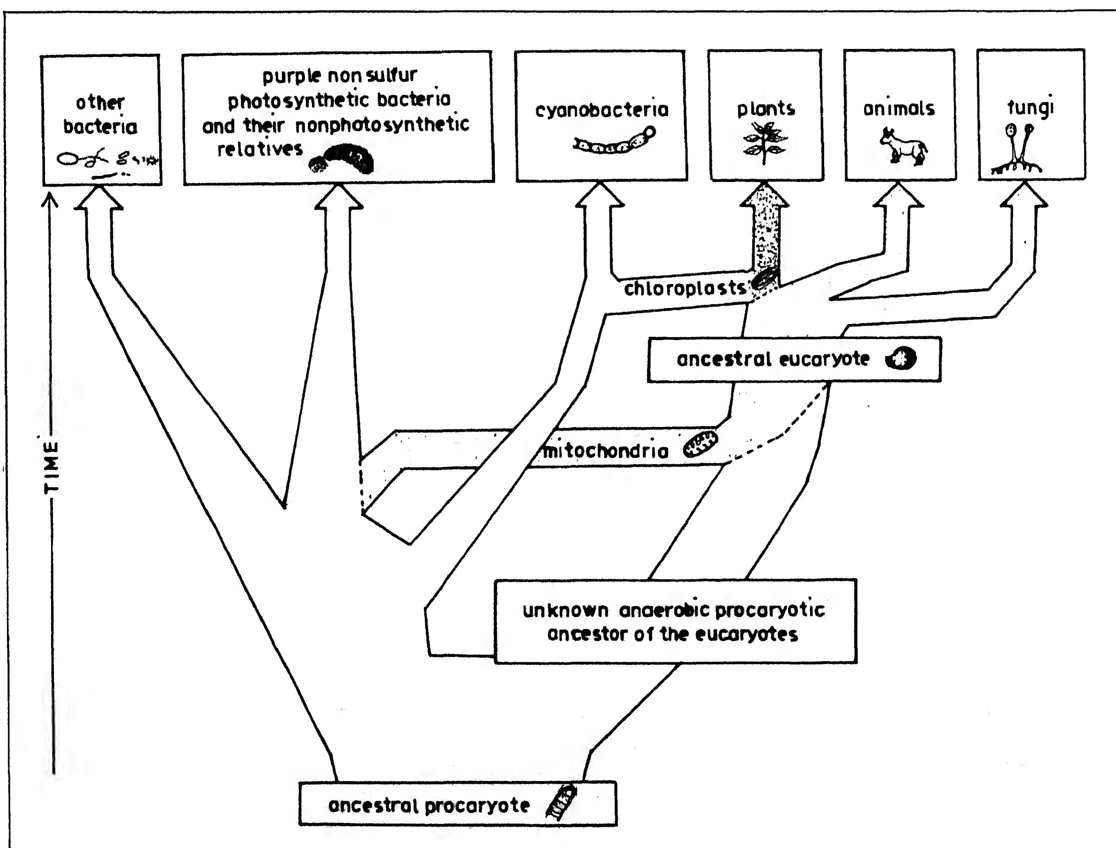


***Figure 3** Cells of higher organisms, such as flowering plants are far more complex than the earlier simpler bacterial cells. They are believed to have arisen as co-operatives of several cells from different evolutionary lineages that came together to constitute the more complex entities.*

Life originated by the elaboration of co-operation amongst teams of molecules - proteins, nucleic acids, lipids. The important new ability of using oxygen to speed up living processes was similarly a consequence of a new kind of mutualism. This was the formation of a single organism out of a merger of two different kinds of bacteria (*Figure 3*). The partners in the merger probably related to each other as prey and predator. The prey bacterium may have been a tough organism - like *Thermoplasma* surviving the hot and acidic waters such as those of the hot springs of the Yellowstone National Park, USA. The predator may have been a bacterium that had the ability to use oxygen, like *Bdellovibrio* which attaches to and then enters its victim's innards by rotating like a whirling drill. After they have used the material resources of their prey to make their own proteins and nucleic acids, *Bdellovibrio* come out by rupturing the empty cellular bags of their ruined hosts.

***Figure 4** Presumed pathways of evolution of the more complex cells that constitute the bodies of fungi, plants and animals.*



It is now generally accepted that mitochondria must have been independent, aerobic bacteria that have now become an integral part of the confederation with their larger former victims who provide the cytoplasm and the nucleus.

It appears that some descendants of such predators evolved to practice restraint. They contented themselves by consuming the expendable waste products, such as oxygen, rather than the entire body of the victim. Thus may have evolved a relationship of mutual advantage, with the former predators helping the host get rid of unwelcome oxygen. Inside the cells of higher plants and animals, oxygen is used in organelles called mitochondria. These mitochondria are wrapped inside their own membranes, have their own nucleic acids and divide independent of the whole cells. It is now generally accepted that these mitochondria must have been independent, aerobic bacteria that have now become an integral part of the confederation with their larger former victims who provide the cytoplasm and the nucleus (*Figure 4*).

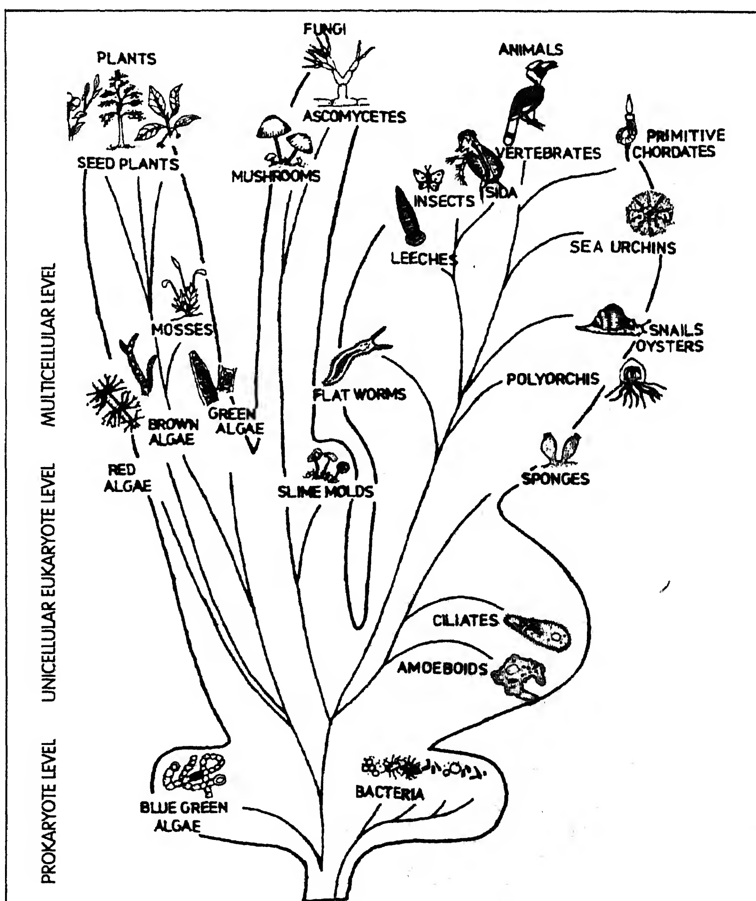


Figure 5 Evolutionary tree of life. All the major groups of simpler organisms that arose in the remote past continue to survive along with the more complex, more recently evolved groups, resulting in an ever increasing diversity of designs.

Suggested Reading

Lynn Margulis, Dorion Sagan. Microcosmos: Four Billion Years of Microbial Evolution. Allen & Unwin, London. 1987. pp 301.

Higher plants also have another kind of organelle inside their cells — plastids which house the green pigments used in trapping light energy to split a molecule of water into hydrogen and oxygen. The plastids seem to be descendants of grass-green bacteria like the *Prochloron*. *Prochloron* is an enormous bacterium loaded with green pigments similar to those of higher plants. Today *Prochloron* coats the sedentary, lemon-shaped marine animals called *sea squirts*, and possibly supplies them with some nutrients. Perhaps relatives of *Prochloron* were eaten by many kinds of bacteria. Some of the victims must have resisted digestion, and those that stayed alive, eventually evolved into plastids. Today this co-operative partnership has achieved tremendous success, with green plants being the most abundant form of life over most of the landmass (*Figure* 5).

Perhaps relatives of *Prochloron* were eaten by many kinds of bacteria. Some of the victims must have resisted digestion, and those that stayed alive, eventually evolved into plastids.

The ability to use oxygen greatly quickened the pace of life. This added yet another major way of life to the repertoire of living organisms. Some of the oxygen imbibing creatures could now actively feed on other organisms. So along with decomposers and photosynthesizers, the earth began to support organisms that grazed or preyed on others.

Address for correspondence
Madhav Gadgil
Centre for Ecological Sciences, Indian Institute of Science,
Bangalore 560 012, India.

Precaution in time of cholera epidemics ... "The Allahabad *Pioneer Mail* says that an experiment is in progress in several of the larger gaols of the Punjab, which may have important results in the future. It has been one of the ordinary precautions in time of cholera epidemics to boil the drinking water supplied to prisoners. To ascertain whether it might not be advisable always to boil the drinking water, the Lieutenant-Governor has ordered that a certain number of the prisoners should be given boiled, and an equal number unboiled, water the results being reported at the end of the year. If these are as expected, the reduction in the fever death-rate should be followed by a similar reduction in mortality from dysentery and diarrhoea."

(first appeared in *Nature*, 12 September 1895.)

Geometry

2. A Circle of Ideas

Kapil H Paranjape

In this article the author addresses the origins of trigonometry and the idea of limits. The concept of 'limit' is crucial in the development of integral calculus, the subject which deals with the measurements of lengths, areas and volumes of general figures. What emerges is that the roots of trigonometry and integral calculus are already implicit in the early geometrical studies.

After spending about a decade at the School of Mathematics, TIFR, Bombay, Kapil H Paranjape is currently with Indian Statistical Institute, Bangalore.

In the previous article we looked at the origins of synthetic and analytic geometry. More practical minded people, the builders and navigators, were studying two other aspects of geometry—trigonometry and integral calculus. These are actually algebraic and analytic studies with the initial input coming in a left handed (right-brained[1]) way.

[1] It is the right half of the brain that is supposed to do spatial thinking and control the left hand. This perhaps gives one explanation why so many left handers are good tennis players.

Trigonometry

Circle: The locus of all points in a plane which are equidistant from a given point.

Quite independent of the rigours of Euclid's synthetic geometry, the geometry of the circle was extensively studied by travellers and builders. The astronomers and navigators of ages past could take one look at the stars and figure out the time, date and their location[2]. This circle of ideas revolves around studying the points on a circle. There are, broadly speaking, two classes of methods for fixing a point on the circle. (Exercise: Quickly figure out these two before reading the next paragraph.)

[2] Nowadays we rush to the quartz watch instead—perhaps because pollution has made it impossible to see the stars.

One class is the 'constructible' one, of which an example is as follows: Choose a point P on the circle and a line l not containing

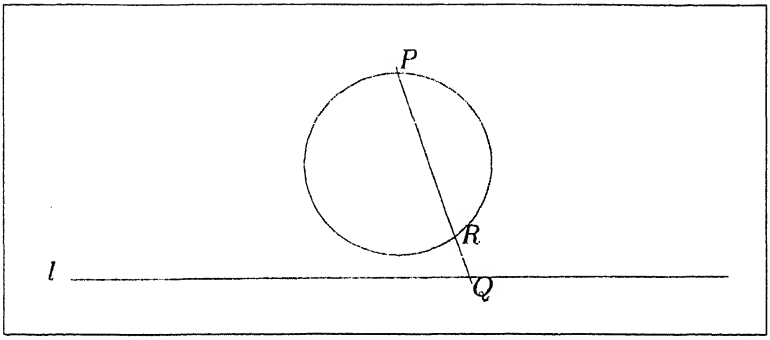


***Figure 1** Rational parametrisation of the circle.*

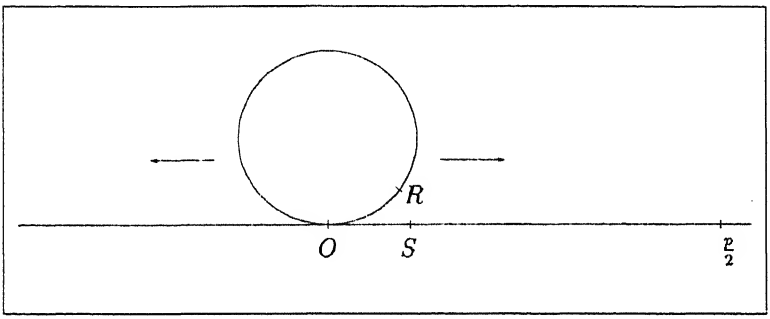


***Figure 2** Unrolling the circle.*

P. Each point Q of the line l *uniquely* fixes a point of the circle. This is the 'other' point R of intersection of the line PQ with the circle (see *Figure 1*). The other class involves unrolling the circle (see *Figure 2*); this can be done by *angular* parametrisation (Exercise: why is this called angular?). In this method each point R of the circle is represented by a collection of points of the form $S \pm n.p$ on the line where S is some point on the line, p is the perimeter of the circle and n is a natural number. (Here $a \pm n.p$ denotes the translation of the point a towards the left/right by the distance $n.p$.)

Quite independent of the rigours of Euclid's synthetic geometry, the geometry of the circle was extensively studied by travellers and builders. The astronomers and navigators of ages past could take one look at the stars and figure out the time, date and location.

The advantage of the first method is both practical and philosophical. From the practical perspective, only that which can be constructed is useful; from the philosophical perspective the unrolling of the circle is an operation which is outside the axiomatic setup (some work has to be done to prove this!). The advantage of the second method is that it is intuitive and aesthetic; it fully captures the symmetry of the circle which is broken by the first method. So how do we reconcile the two methods?

Construction of Regular Polygons

While the circle is an endless source of geometrical ideas we now describe another historically important problem—the construction of regular polygons. Let θ_n denote the angle subtended by the side of a regular n-sided polygon at its centre. One can then show using the addition laws above that $t_n = t(\theta_n)$ satisfies an equation of degree $n-1$. Some number theory can be brought in to show that this equation can be solved by a succession of square roots (of sums of squares) if and only if $n = 2^m q$ where q is a product of distinct Fermat *primes*. This gives Gauss' famous theorem about the constructibility of polygons. In particular, this shows that the 17-sided regular polygon is constructible, a fact realised by Gauss at the age of 19!

To fix things we choose a point P of the circle and let the line l be the tangent line to the circle at the anti-podal point O (if d denotes the line joining P to the centre of the circle then l is the line through O which is perpendicular to d; see *Figure 3)*. We choose coordinates on the line so that O is the origin. Then Q in the first construction represents a number t. The unrolling procedure assigns to each point of the circle other than P, a point S on l with coordinate θ between $-p/2$ and $p/2$. The combination then gives us an assignment $\theta\,(t)$ for every number t thought of as a point on the line l; those who prefer the second method could also think of the assignment $t(\theta)$. In order to realise the rotational symmetry in the constructive approach we must be able to find $t_3 = t(\theta\,(t_1) + \theta\,(t_2))$; in other words we must be able to express the combination of two rotations (denoted by $\theta\,(t_1)$ and $\theta\,(t_2)$) in constructible coordinates. The construction is sketched in *Figure 3* and the formula is

$$t_3 = [4(t_1 + t_2)] \,/\, [4 - t_1 t_2].$$

It is an easy exercise in coordinate geometry to verify this (braver people may also attempt a proof using Euclidean geometry alone).

The above formula summarises the *essence* of trigonometry. To put things in a more familiar setting we note that

$$t\,(\theta) = 2 \tan\,(\theta/2).$$

The above formula then becomes the familiar addition law for tan. We note that the coordinates of the point $(x,y) = (\sin(\theta), -\cos(\theta))$ are expressed in terms of $t = t(\theta)$ as

$$(x,y) = (\,4t \,/\, [t^2 + 4], [t^2 - 4] \,/\, [t^2 + 4]\,).$$

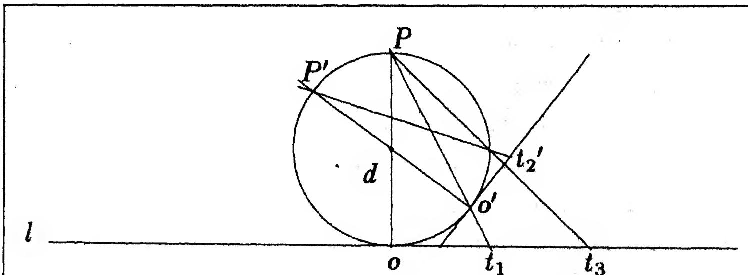


Figure 3 The addition law.

Conversely, given (x,y) such that $x^2 + y^2 = 1$ we have

$$t = 2x/(1-y) = 2(1+y)/x$$

In other words we can work interchangeably between the t coordinate and the (x,y) coordinates for the circle. (Exercise: derive the addition law for sin and cos using the above formulae.)

In different parts of the world mathematicians came upon different versions of the above formulae (and gave us a seemingly endless series of school problems on trigonometry). A complete exposition was given in the works of Indian and Arab mathematicians, but it was left to de Moivre and Euler to put the finishing touches as we shall see later.

In different parts of the world mathematicians came upon different versions of the trigonometric formulae. A complete exposition was given in the works of Indian and Arab mathematicians, but it was left to de Moivre and Euler to put the finishing touches.

This is the Limit

Limit: (of a sequence) A point such that the points of the sequence eventually approach it to within any previously specified distance.

Some of the Greek mathematicians were quite confused! For example, let us take an empty cup and put it under a tap. Assume that it is half full in a minute. It is then 3/4-th full in another half minute and 7/8-th full a quarter minute after that and so on. Will the cup ever be full? In other words, can the sequence {1/2, 3/4, 7/8, 15/16,...} be said to *become* 1 in some sense? The problem here is clearly an abstract mathematical one—most thirsty people would grab the cup after some time!

This enigma was resolved by that famous Greek mathematician Archimedes who introduced the axiom: *Given a succession of points, A_n for $n = 1,2,3,...$ and a point B so that A_{n+1} is between A_n and B for all n. There is a point C between A_n and B for every n so that if D also has the same property then D is between C and B (see Figure 4). (In other words C is the limit of the sequence A_n)*

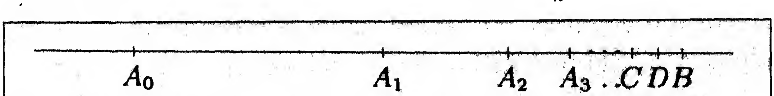
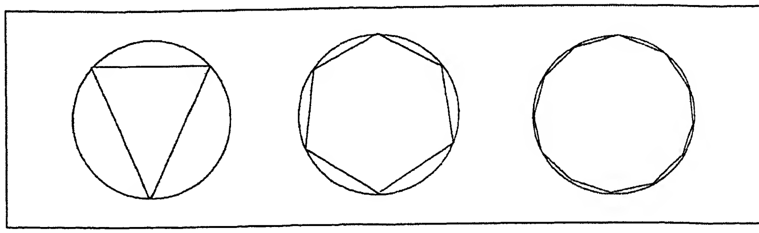


***Figure 4** The axiom introduced by Archimedes.*

Figure 5 Filling out a circle.



It has one of the basic properties of axioms in that it conforms to our picture of the world around us. However, it was unacceptable to a number of Greek mathematicians since it asserted the existence of a point without giving a construction. We use it since it is quite essential to much of modern mathematics and its applications.

Not every figure is measurable and non-measurable figures can behave in strange ways. A ball can (in principle) be cut into three non-measurable pieces which when put together in a different way give a ball of twice the size!

With this axiom in hand we can try to find areas of figures and volumes of solids, of varied shapes. The fundamental idea is that of *approximation*. We find a sequence of objects which we can measure exactly and which successively give better and better approximations to the value we want (*Figure* 5). But this method begs the question—how do we know that these values approximate the value we want?

A number of different approaches to measurement were tried out till Lebesgue finally resolved the question at the beginning of this century. He answered the question—what are *all* the figures that we can call *measurable*? We first look at all the exactly measurable (constructively measurable) figures like polygons, within the given figure F (see *Figure* 5). Let $i(F)$ denote the smallest number greater than all of these measures. (The existence of such a number is guaranteed by the axiom given above). Similarly, let $o(F)$ denote the largest number less than the measure of all exactly measurable figures that enclose the given figure (see *Figure* 6). If $i(F) = o(F)$, then we say F is measurable. Lebesgue then showed how this gives rise to a consistent theory of measurement. (Exercise: By this method try to find a good approximation to the area of a circle. Show that it is good say up to the 2nd decimal place.)

A word of warning—not every figure is measurable and non-measurable figures can behave in strange ways. A ball can (in principle) be cut into finitely many non-measurable pieces which

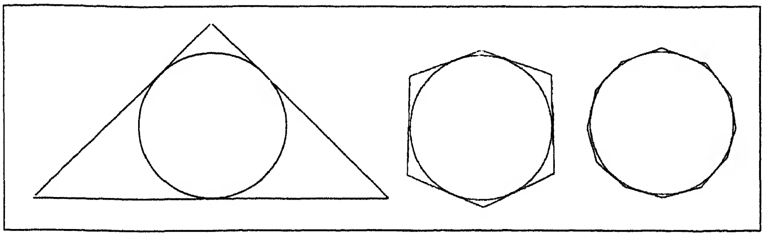


Figure 6 Enclosing a circle.

when put together in a different way give a ball of twice the size! This is the so called 'Banach-Tarski paradox'. However, it is not easy to sketch a non-measurable figure! It would seem that a figure that can be sketched is measurable. In fact there is a device called the *pantograph* which will give the area enclosed by a closed curve if we trace the curve. (Exercise: Re-invent this device!). So I cannot show you a picture of a non-measurable figure.

This study of areas and volumes is today called measure theory and is a fundamental branch of analysis and probability theory. A slightly different and more geometric approach led to integral calculus as we shall see in a later article.

The study of areas and volumes is today called measure theory and is a fundamental branch of analysis and probability theory.

Summary

Trigonometry is summarised by the single formula that gives the addition law. All other identities in trigonometry follow from either this one (which summarizes the relation between the constructible co-ordinates and the intuitive one on the circle) or the relation between various different constructible coordinates on the circle. The main reason for the unending sequence of school exercises is to develop algebraic skills.

Measurement of lengths, areas and volumes is not too difficult for the well-known types of figures (polygons, prisms, pyramids, etc.). We can use these figures to "fill up" more complicated figures to measure them. To do this we need to introduce numbers that are limits of other numbers, in other words *real* numbers.

Let us plunge ahead! Is the parallel axiom justified? Are coordinates still valid without it? How can we perform experiments to find out if our (Euclidean) intuition is correct? Await the exciting next instalment.

Address for correspondence
Kapil H Paranjape,
Indian Statistical Institute,
8th Mile, Mysore Road,
Bangalore 560 059, India.

Know Your Personal Computer

2. The Personal Computer Hardware

S K Ghoshal

Siddhartha Kumar Ghoshal works with whatever goes on inside parallel computers. That includes hardware, system software, algorithms and applications. From his early childhood he has designed and built electronic gadgets. One of the most recent ones is a sixteen processor parallel computer with IBM PC motherboards.

This article surveys personal computing with the IBM personal computer as a platform to discuss details of hardware.

Introduction

The personal computer (PC) is the most widespread and popular computer because it runs all kinds of applications. In fact, if there is an application package that does not have a PC variant it is wise to not get familiar with it as its host may become obsolete and the package not survive. PCs will take a long time to get obsolete. They only get smaller, cheaper and more powerful as the years go by. Eventually, all the applications that people need will become available on PCs.

PCs can be connected to all types of peripherals and equipment. If any device does not interface with a personal computer, it may not be worth buying. In fact one should be sceptical of the device because a PC has an open architecture for which peripherals are easily developed. A device that does not plug into a PC does not live long. Such devices can be had from many vendors. They become cheaper and more powerful with time as their technology improves.

Address for correspondence
S K Ghoshal,
Supercomputer Education and Research Centre,
Indian Institute of Science,
Bangalore 560 012, India.

PCs come in all sizes, prices and capabilities. Some are large machines with a huge, fast, primary memory and a large backup disk which serves as secondary memory. Such PCs are capable of running an interactive operating system that hundreds of users can simultaneously use over a network. The tiny laptop PCs, barely larger than a pocket calculator in size, that run for hours on a rechargeable battery are also widely used. The base architecture

A truly open system

All IBM PCs are compatible. Programs compiled in any one will run on any other. This is called *portability*. Almost any hardware component in the PC can be upgraded to a more powerful and modern variant and yet all the old programs run on the new system. This is called *scalability*. Old operating system, compilers and other system programs can be replaced with new ones without disturbing the way applications are run on the PC platform. This is called *interoperability*. These three properties make the IBM PC an open system. You can buy and use it in peace for years. You can upgrade it whenever you need it and can afford it. PCs do not get obsolete. Like a bicycle, all of it is never discarded. Components which are old are replaced with new and improved ones.

ıd organization of system software remain the same across all of ıem and this is what we will study in this article and the ones to ›llow.

ersonal computers are a result of the tremendous advances made ı very large scale integration (VLSI) design tools and implemenıtion technology. This had two effects. First, powerful micropro-ɜssors were made in small areas of silicon. Second, system ıtegration techniques allowed printed circuit boards to be mass-roduced, populated with the semiconductor components and :sted, resulting in highly reliable systems which could be sold at low price. This trend continues and personal computers keep ɜtting smaller, more powerful and more affordable. People who rite system software have realized that programs should be ritten in such a way that they can be used, understood and run

PCs will take a long time to get obsolete. They only get smaller, cheaper and more powerful as the years go by.

Why IBM PC?

Personal computers are there because people want them (particularly the types that do not consume much electrical energy and don't need air-conditioning and other types of protected environments) at affordable prices and today's technology can mass-produce inexpensive but reasonably powerful ones. Most of them work reliably without much maintenance. The developments in personal computers were inevitable but the reason that the IBM PC is so popular is that its architecture is open and its standards are well-defined and published. There are therefore many vendors developing hardware for the PC and many billions of dollars worth of software runs on this platform.

If I did it again

Often pioneers assign bad names to what they invent and repent later in life. Ken Thompson was asked what his first step would be if he were to write Unix (Unix is a trademark of Unix Systems Laboratories) again. He replied: "I would call it create". He was referring to the creat *system call* of Unix. Unix is the most portable operating system today. That is because Ken and others had designed the system calls and other internals of Unix so well that it has survived the test of time, has spread across virtually every computer system that exists today and has flourished among many different user communities. Unix also runs on IBM PCs. We will discuss Unix in subsequent articles in this series and also look at the system call in Unix that creates new files or rewrites old files. But we will have to call it creat.

System call is a request from a user's program to the operating system of a computer for a service such as creating a file, deleting a file etc.

People who write system software have realized that programs should be written in such a way that they can be used, understood and run on many different machines.

on many different machines. Thus system software and their applications are more standardized than they were a few years ago. Both these trends are good for computing in general and personal computing in particular.

However, while studying personal computers and the organization of their system and application software, it must be borne in mind that many developments that took place had a historic reason and many more were idiosyncratic in nature. The external circumstances and individual mind-sets that led to these changes no longer exist. So if one had to do it today all over again, the

How they missed the opportunity

It could have been the DEC PC. If they had only listened to engineer David Ahl at Digital Equipment Corporation (DEC). In 1974, he proposed that the company produce an inexpensive version of its PDP-8 minicomputer and sell it to computer enthusiasts for $5000 a piece, at no loss for DEC (DEC and PDP are registered trademarks of the Digital Equipment Corporation). Top management shot down the idea. They thought that it would be foolish for an individual to buy a computer. She would rather buy a dumb terminal that connected her to a powerful mainframe. That was the trend in computing those days. The VLSI revolution had just begun. Not many were aware of its potential. Few believed personal computers could be sold to the masses. Had Ahl's proposal been taken up, the PDP architecture would have played the same role in the history of personal computing as the 8088/80386/80486 series from Intel!

The First Personal Computer

ırs ago, only electronics hobbyists y interested in personal computers only in the pages of magazines like ɔnics and in the laboratories of people ılding them. Some companies sold ›wer supply, keyboard and monitors) to hobbyists. Altair from MITS of Albuquerque, New Mexico, USA is the first personal computer which sold in volume. Introduced in 1975, it had the 8-bit Intel 8080 as its CPU and 256 bytes of memory. A young man wrote a BASIC language interpreter for this machine. His name: Bill Gates.

ld be quite different.

sible, I will try to explain why things were designed vere and how they changed as technology evolved. ction, we present an overview of the PC hardware.

re

ɔrtant component in the IBM PC is the *motherboard*. ;ular printed circuit board (PCB) which has the hips) or 80486 CPU, the primary memory, the ɔs that carry out operations such as direct memory interrupt handling and keeping track of the system m integration technology improves, keeping pace

›ownsizing was hard to do those days

ıicrocomputers grew more powerful, sold well and finally mainframes. Mainframes did not take advantage of the They did not shrink their hardware in size and make their modular, tight and portable (this whole operation, done ;ystem designers is called *downsizing* these days). All d supercomputer vendors failed in this aspect. IBM, Data ol Data, Texas Instruments and Cray Research attempted ›ir popular models but without much success. They some- derstand the micros. Downsizing has been perfected by tions by now, as system software and applications must ɔlatform, or else perish.

Personal Computing – the Apple way

One company that has refused to follow IBM and has created a niche for itself is Apple. Its founders, Steve Jobs and Steve. Wozniak were pioneers in personal computing. They created personal computers before IBM got into the game. Apple uses the Motorola 68000/68020 series of microprocessors as their CPU. They are much easier to use than IBM PCs, thanks to their excellent icon-based graphical user interface. Apple did not make its architecture open. In India, they are popular only with desk top publishers.

What is DMA?

Copying data between memory devices (particularly between primary and secondary memory devices) is an operation very frequently used in a computer system. One can always use the CPU itself to copy data. But that would be wasting the hardware resources of the CPU and is also very slow. Thus every computer system has a number of channels bypassing the CPU, to directly access memory and copy data. This mechanism is called *direct memory access* or DMA. The channels are called DMA channels.

with advances made in VLSI technology, all these controller chips get incorporated within complex VLSI chips called application specific integrated circuits (ASICs). A modern motherboard has only about 4-5 chips apart from the CPU. Therefore they consume less power and work more reliably than their ancestors. They even cost less since ASICs can be mass produced.

The electrical signals produced by the CPU are weak and they cannot traverse long lines without getting severely attenuated. So these signals are amplified (or *buffered*, in digital electronics parlance) using special chips called transceivers (which can buffer in both directions and are used for data lines) and address latches (which can retain an useful address output by the CPU and can thus be used to wait for slow memory to respond to a fast CPU) which are also present on the motherboard. In modern motherboards there are many sequential digital *finite state machines* (FSMs) which serve as an interface between CPU and memory and input/output (I/O) devices. They help the CPU work with a high throughput while working with slow devices. Just as a power transformer with multiple secondary windings steps down 220V and supplies 12V, 5V, 3V etc at different ampere ratings, the FSMs distribute the CPU's memory bus into a number of specialized buses with different speeds and widths. Thus maximum throughput is obtained from the system and a uniform view of the memory is projected to the CPU, even though it is physically heterogeneous with different types of devices with various bus speeds and widths. One of these buses which is relatively slow and only 8-bit wide, terminates on the motherboard itself and connects to an erasable programmable read-only memory (EPROM) device. This device has some programs that are run while initializing the motherboard and other programs which serve as a low-level operating system. These programs are collectively called *Basic Input Output System* (BIOS).

A high-speed 32-bit wide bus connects the CPU, through the cache controller FSM, to up to 512 Kilobytes of SRAM cache

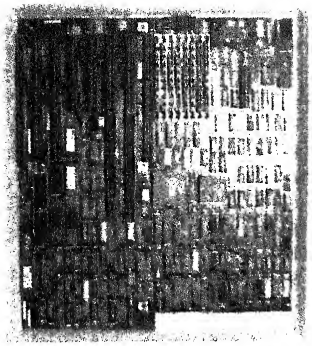
Is BIOS Hardware or Software?

The original IBM PC BIOS was a trademark of IBM. IBM also retains copyright of that BIOS. Now BIOS is written and sold by many vendors. When you buy a motherboard, you get BIOS along with it. BIOS is closely associated with the hardware and needs to be changed or augmented if the hardware is changed in a major way. It remains physically with the hardware in that it is kept in EPROMs that are plugged into the motherboard. It does not have to be loaded from an external device every time the computer is turned on. Some people regard BIOS as part of the hardware. We however, take a middle path and denote BIOS by a term *"firmware"*, to designate that it is in between hardware and software.

memory that can be present on the motherboard. Yet another medium-speed 32-bit bus connects the CPU, through DRAM controllers, to banks of dynamic RAMs integrated as single in-line memory modules (SIMMs) which constitute the primary memory of the computing system. SIMMs are removable from the motherboard. Many other buses connect the CPU to different peripheral support and other controller chips that are present on the motherboard.

Personal computers are a result of the tremendous advances made in very large scale integration (VLSI) design tools and implementation technology. This had two effects. First, powerful microprocessors were made in small areas of silicon. Second, system integration techniques allowed printed circuit boards to be mass-produced, populated with the semiconductor components and successfully tested.

A number of buses are brought out of the motherboard as edge-connectors. They are used to plug in add-on cards and extend the architecture. IBM PC supports the world's largest variety of add-on cards available from a wide range of vendors at affordable prices. The old and slow *Industry Standard Architecture* (ISA) bus which had two varieties 8-bit and 16-bit wide respectively, the 32-bit *Extended Industry Standard Architecture* (EISA) bus and the 32-bit high-speed *Peripheral Component Interconnect* (PCI) bus are some popular standard buses. A couple of these edge connectors are taken up by the graphics adapter and the hard disk controller. The rest are left free for the user to plug in adapters of his choice and requirements. The motherboard has a DIN socket into which a 5-core cable from the keyboard plugs in. It also has a polarized



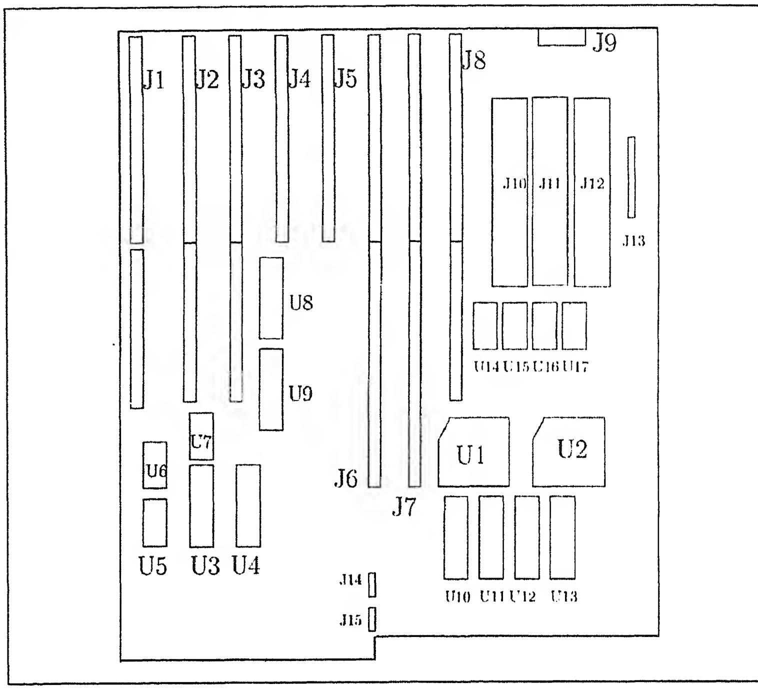


Figure 1 Photograph of an Intel iSBC386ATZ motherboard..

Figure 2 Floor-plan of the Intel iSBC386ATZ motherboard.

power supply connector (so that one cannot connect it in reverse and blow up all the hardware in the motherboard) to feed it power from a *switched mode power supply* (SMPS). Once the keyboard, power supply, disk adaptor with drives, graphics adaptor and monitors are connected, the PC is a complete computer ready to switch on and be used. *Figure 1* shows an old-generation 80386-based motherboard from Intel. *Figure 2* depicts its floor-plan. U1 is the 80386 CPU. U2 is the 80387 numeric co-processor. U3 and U4 are the DMA controllers. U5 and U6 are the interrupt controllers. U7 is the programmable interval timer chip that helps keep track of the system time and generates many other kinds of timing interrupts that are used by the system software. U8 and U9 are EPROMs that contain BIOS. U10, U11, U12 and U13 are *programmable array logic* (PAL) chips that implement the different FSMs. U14, U15, U16 and U17 are transceivers. J1, J2 and J3 are 16-bit wide ISA slots. J4 and J5 are 8-bit wide ISA slots. J6 and J7 are 32-bit wide Intel's own slots. (which never became very popular). J8 is a 16-bit wide ISA slot. J9 is the keyboard connector. J10, J11 and J12 are the SIMM module sockets. J13 is the power supply connector. J14 is the speaker connector. J15 is the key-lock connector.

Compatibility

The first PC from IBM, released in 1981, had an Intel 8088 CPU working at 4.77 MHz clock speed, in a motherboard which did not have any FSM or cache memory and only had 8-bit ISA slots. Any program that ran on that platform, can run on any modern motherboard. It uses all the resources present both on the motherboard and across PCI or EISA buses, to deliver, on an average, more than 20 times the performance the original one did.

What is a Bus?

The CPU accesses memory and exchanges data with input/output devices using a set of wires called a *bus*. Each wire conveys a bit. If it is at +5Volt potential with respect to the ground line, then it represents a 1. If it is less than 0.6V potential with respect to the ground, it conveys a 0. The number of lines in a bus is called its width (see *Figure 3*). A number of ground lines are also run along with the signal lines in order to nullify any effect of difference of ground voltages at the two ends of a bus. The ground lines are not counted in the width of the bus. If a bus conveys the address sent out by a CPU, it is called an *address bus*. It is unidirectional. Its direction of signal flow is always from the CPU to the memory, and never the other way. If a bus carries data that is exchanged between the CPU and the memory, then it is called the *data bus*. Data buses are bi-directional. A collection of data and address buses is simply called a *bus*. *Figure 4* shows a CPU accessing a memory with 2^{32} bytes using an address bus that is 32 bits wide and a data bus which is 8 bits (i.e. one byte) wide. The READ, WRITE and WAIT lines are together called the *control signals*. Often power supply lines carrying many amperes of +5V, important control signals and other signal lines like clock and interrupt lines (lines by which devices can send signals to the CPU) are included in a bus. Buses follow a specification that lays down the geometrical arrangement of the wires, the maximum permissible length, the maximum number of devices that can be connected to it and other details. By common usage of the term, a *N*-bit wide bus means a complete bus, whose data-bus width is *N*-bits. Thus, *Figure 3* shows a 4-bit bus.

In subsequent articles we will learn more about the hardware and software of the IBM PC. Write to me if you want more information or have any questions or comments about this article.

***Figure 3** A unidirectional bus of width 4. The four wires and the ground wire as shown in (a) form a bus; it is normally represented as in (b). The digit 4 above the / symbol indicates that the bus width is 4 and the arrow indicates that the bus carries signals from left to right.*

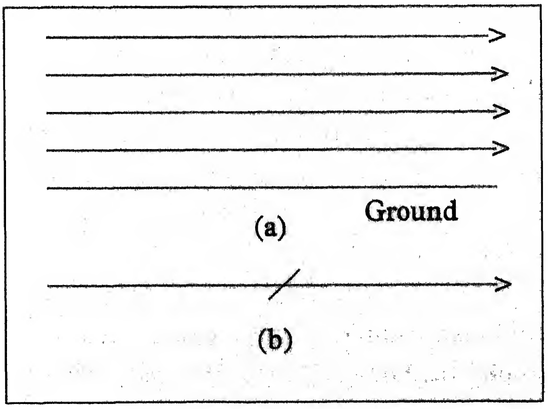
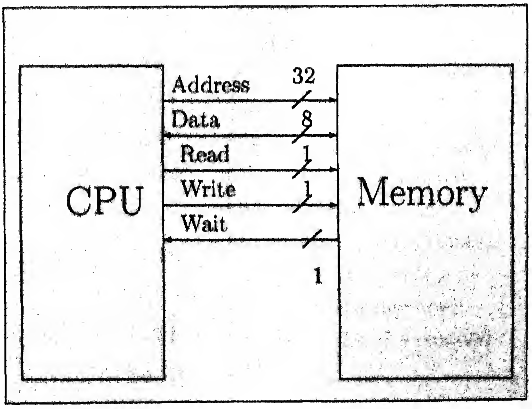


***Figure 4** CPU accessing memory using a bus.*



Learning Organic Chemistry Through Natural Products

2. Determination of Absolute Stereochemistry

N R Krishnaswamy

N R Krishnaswamy was initiated into the world of natural products by T R Seshadri at University of Delhi and has carried on the glorious traditions of his mentor. He has taught at Bangalore University, Calicut University and Sri Sathya Sai Institute of Higher Learning. Generations of students would vouch for the fact that he has the uncanny ability to present the chemistry of natural products logically and with feeling.

Though the ultimate method of determining the absolute stereo-chemistry of a compound is X-ray diffraction analysis, an organic chemist gets more satisfaction from a chemical approach which also generates new chemistry.

Address for correspondence
N R Krishnaswamy,
Visiting Professor,
NMKRV College for Women with PG Centre,
Jayanagar III Block,
Bangalore 560011, India.

Chemical methods to determine the conformations and absolute configurations of menthol, a cyclohexane derivative with 3 chiral centres, are described.

Structures of organic compounds are usually determined using data generated by chemical and instrumental methods. A chemist then invariably attempts to confirm the proposed structure by synthesis. The above approach was described in the previous part of this series, using geraniol as an illustrative example. This molecule had sufficient complexity to highlight the steps of the deductive process. However, geraniol lacks an important feature present in many organic compounds, in general, and in natural products, in particular. The molecular structure of geraniol is superimposable on its mirror image and hence it is achiral. The problem of structure determination has an added dimension in molecules which are chiral.

Chirality or "handedness" of organic molecules usually arises due to the tetrahedral geometry of tetra-coordinate carbon. If the four substituents on a carbon atom in a molecule are different, a chiral centre is present. In such molecules, there are two ways of arranging the substituents leading to non-superimposable structures. These are called enantiomorphs. In such chiral molecules, it is not enough to identify the bond connectivities of all the atoms. We also need to find out the precise stereo-chemical relationship involving the substituents (or equivalently, the absolute configuration at the chiral centre).

The problem becomes more complex if more chiral centres are present in the same molecule. For a molecule with n asymmetric

centres, there are theoretically 2^n possible stereo-isomers. In this part of the series, we will discuss how the absolute stereochemistry of a compound can be delineated using chemical methods, with the help of an example containing multiple chiral centres.

Molecules do not necessarily have rigid geometries. They can adopt many flexible 'conformations'.

The example we have chosen addresses another interesting structural problem. Molecules do not necessarily have rigid geometries. They can adopt many flexible 'conformations'. In ring systems, some conformations are especially preferred. The molecule we have chosen illustrates concepts associated with ring conformations as well as absolute configurations at chiral centres.

Menthol - a Chiral Cyclohexane Derivative

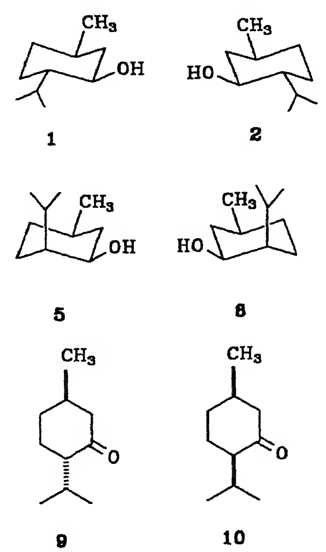
(–) Menthol is a constituent of the peppermint oil which is the essential oil of *Mentha piperita*.

As our illustrative example we have chosen Menthol which is a monocyclic monoterpenoid alcohol. It is 2-isopropyl-5-methylcyclohexanol and has three chiral centres as shown in *Scheme 1*. Therefore, 2^3 or eight optically active stereoisomers of this structure are possible and are known. These are (+) and (–) menthol, (+) and (–) neomenthol, (+) and (–) isomenthol, and (+) and (–) isoneomenthol. Further, being cyclohexane derivatives, menthol and its stereoisomers also exhibit conformational isomerism. Thus, this example can illustrate the principles involved in conformational analysis as well as configurational assignments.

The problem is to assign the correct stereostructure to each of the eight isomers mentioned above. The first step would be to find out the relative configurations of the three asymmetric centres in each enantiomorphic pair of the four diastereoisomers. Determination of the absolute configuration would then lead to a unique stereostructure for each and every optical isomer. Scheme 1 shows all the possible structures.

Enantiomorphs do not differ in physical or chemical properties except in the sign of optical rotation, whereas diastereoisomers differ in physical and chemical properties.

Examination of the structures shows that compounds 1 and 2 which form a pair of enantiomorphs, are degenerate (that is they have the same energy) and should represent the thermodynami-



Scheme 1

cally most stable enantiomorphic pair among the four pairs of diastereoisomers. Incidentally, it should be noted that enantiomorphs do not differ in energy content whereas diastereoisomers do. Compounds **1** and **2** are thermodynamically the most stable because all the three substituents attached to the cyclohexane framework are equatorially oriented. Therefore, the strain due to steric interactions between them, if any, will be at a minimum. On the other hand, each axial substituent introduces a finite amount of steric strain thus increasing the energy of the system. In structures **7** and **8**, two of the substituents, namely the hydroxyl and the isopropyl groups are axially oriented and these should possess greater energy than **1** and **2**.

Cyclohexane prefers the chair conformation and bulky substituents opt for the equatorial position.

An axial substituent may encounter severe 1,3-diaxial steric and/or repulsive polar interactions thus causing a strain in the system.

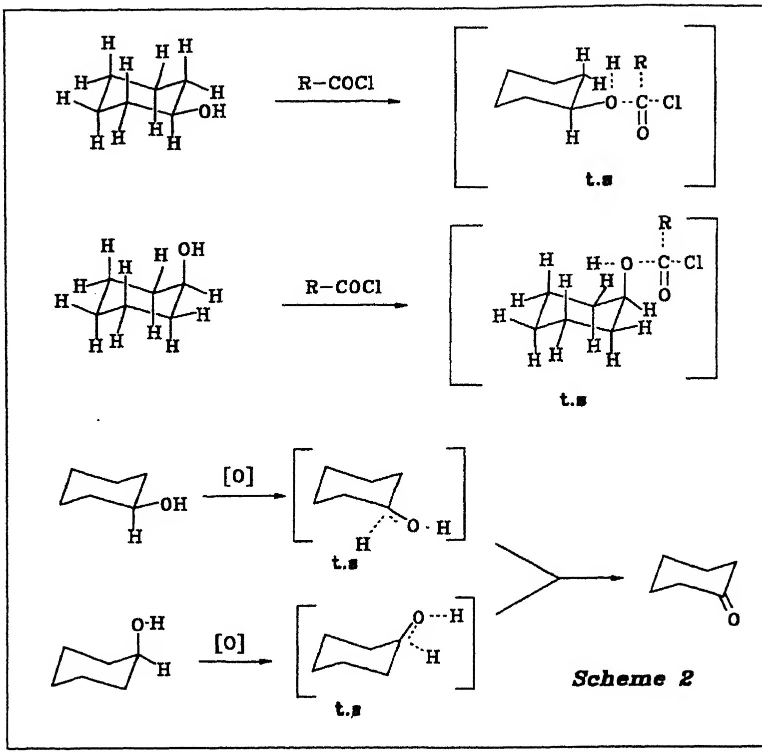
An idea of the free energy contents and therefore, relative thermodynamic stabilities is given by the differences in boiling points, densities and refractive indices of the different stereo-isomers. As the energy content decreases, that is as the stability increases, the boiling point, density and refractive index decrease. An empirical relationship correlating thermodynamic stability with these physical properties is known as the *von Auwers-Skita rule*. A comparison of the physical properties of the four pairs of diastereoisomers

shows that the two enantiomorphic forms of menthol are the most stable and, therefore, these can be assigned the structures 1 and 2.

Menthol and neomenthol both yield, on oxidation, the same ketone, menthone (9). Similarly, isomenthol and neoisomenthol give isomenthone (10). Hence, menthol and neomenthol are epimers differing in configuration only at carbon–1. Since we have already assigned structures 1 and 2 to the two enantiomorphic forms of menthol on the basis of von Auwers-Skita rules, neomenthol can be given structures 3 and 4. In these structures the hydroxyl group takes an axial orientation. By using conformational methods of analysis, Eliel was able to confirm these structural assignments as explained below.

Equatorial cyclohexanols undergo acylation more readily than the corresponding axial isomers. In contrast, the axial isomers can be oxidised at a faster rate than their equatorial isomers, both yielding the same ketone. These observations can be explained on the basis of relative differences in the energies of the transition states. In the acylation reaction, the transition state for the axial alcohol experiences an increase in steric strain due to an increase in the size of the axial substituent. In the transition state of the equatorial isomer, on the other hand, the increase in the size of the substituent does not cause any appreciable increase in steric strain as the group is oriented away from the ring. The situation is just the reverse in the oxidation reaction wherein a sp^3 carbon gets converted into a sp^2 carbon. This leads to a flattening of that part of the ring system and with that any axial-axial repulsion disappears. Thus, in the case of the axial alcohol, there is a decrease in steric strain in the transition state as the oxygen atom of the hydroxyl group leans away from its original vertical position to finally fall into the plane of the ring in the product ketone. In the equatorial isomer, a corresponding decrease in energy is not seen as the hydroxyl group is already, more or less, in the plane of the ring. These changes are pictorially shown in *Scheme 2*.

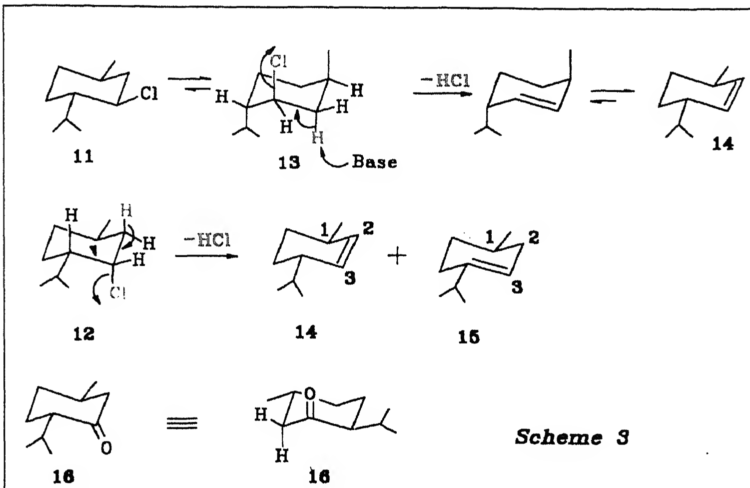
Every reaction has to go through a transition state (t.s.) and the height of the energy barrier separating the reactant and the t.s. controls the rate of the reaction.



Now, it is known that the rates of acylation of the isomeric menthols follow the order: menthol > isomenthol > neoisomenthol > neomenthol. Therefore, in menthol and isomenthol, the hydroxyl group should be equatorially oriented whereas in neomenthol and neoisomenthol it takes an axial position. This is supported by the observation that neomenthol and neoisomenthol undergo oxidation at faster rates than menthol and isomenthol respectively.

The E2 reaction is a one-step concerted process; no reactive intermediates are involved.

Scheme 3 depicts another approach to the same problem. This is based on differences in the rates of base-catalysed E2 elimination of HCl from menthyl chloride **11** and neomenthyl chloride **12**. In this reaction, neomenthyl chloride reacts 200 times faster than menthyl chloride. The E2 reaction is a concerted reaction unlike the E1. The two leaving groups, hydrogen as proton and chlorine as chloride ion, should be *anti-* to each other for simultaneous expulsion so that the reaction path follows a straight line as shown in the Scheme. This can be compared to shooting an arrow



Scheme 3

through a tree forming a straight hole in the trunk of the tree. An *anti-* arrangement of the hydrogen and chlorine is seen only in 12. On the other hand, 11 must first undergo a conformational change into the energetically less favourable conformer 13 where the chlorine is now axially oriented before it can undergo the E2 reaction. That is why 12 reacts several times faster than 11. Another consequence of the stereochemical differences between 12 and 13 is that in 13 only one *anti*-elimination is possible resulting in the exclusive formation of menth-2-ene (14) whereas two possibilities exist in 12 which gives a mixture of 14 and the isomeric menth-3-ene (15); the latter is the major product as it is thermodynamically more stable than 14. The formation of 15 as the major product can be predicted on the basis of the Saytzeff rule.

The change of 11 into 13 involves ring flipping where one chair form gets converted into an alternative chair. This is a conformational change with the configurations remaining unaffected.

The final problem is the determination of the absolute stereochemistry of (–) menthol. As mentioned earlier, this compound can have either structure 1 or 2. The configurations in 1, according to the sequence rule, are 1R, 2S and 3S. Isomer 2, accordingly, has the 1S, 2R, 3R configuration. On oxidation, (–) menthol yields (–) menthone whose absolute stereochemistry can be determined using the octant rule. This semi-empirical rule is based on the relationship between the sign of the Cotton effect in the optical rotatory dispersion spectrum and absolute configuration

The sequence rule formulated by Cahn, Ingold and Prelog is a method of designation of configurations which is not linked to an arbitrary reference compound like the earlier D,L nomenclature.

The ORD phenomenon is the increase in optical rotation with decrease in wavelength of the incident light. If the optically active compound has a chromophore like the carbonyl group near one or more asymmetric centres its ORD spectrum will show the Cotton effect.

of a chiral cyclohexanone. Since (–) menthone shows a (+) Cotton effect, it should have the absolute stereochemistry as in **16.** Therefore, (–) menthol should have the structure **1** and (+) menthol the structure **2.** (+) Neomenthol can be assigned structure **3** as (–) menthol and (+) neomenthol both yield the same ketone, (–) menthone, on oxidation. Therefore, (–) neomenthol is **4.**

A similar approach can be used to elucidate the absolute stereochemistry of the remaining isomers **5-8.**

Suggested Reading

D Nasipuri. Stereochemistry of Organic Compounds - Principles and Applications (Second Edition). Wiley-Eastern. 1994.

Lesson from a mining accident ... At the beginning of the 18th century mining accidents due to broken elevator chains became more frequent. Many scholars including the famous Gottfried Wilhelm Leibniz, tried to improve the iron chains, but without success. Finally a senior mining adviser, W Albert (who was a lawyer by training), came up with the idea of replacing the chains with wire ropes or cables. This made it possible to exploit one of the most important properties of iron — its high tensile strength. (from *Quantum*, September-October 1995)

A tragic mix-up ... John Tyndall, a famous British physicist of the 19th century, could have been among the first to understand the perils of the greenhouse effect. But, alas, that was not to be. One wintry morning in 1893 his young wife Louise gave him a giant dose of chloral instead of the normal big dose of magnesia for his indigestion. Tyndall swallowed the dose and remarked that it tasted sweet. "John, I gave you chloral!", Louise told him. "Yes, my poor darling", Tyndall told her, "you have killed your John". He was dead before sundown. (from *Next Hundred Years* by J Weiner).

Artificial Neural Networks

A Brief Introduction

Jitendra R Raol and Sunilkumar S Mankame

Artificial neural networks are 'biologically' inspired networks. They have the ability to learn from empirical data/ information. They find use in computer science and control engineering fields.

In recent years artificial neural networks (ANNs) have fascinated scientists and engineers all over the world. They have the ability to learn and recall - the main functions of the (human) brain. A major reason for this fascination is that ANNs are 'biologically' inspired. They have the apparent ability to imitate the brain's activity to make decisions and draw conclusions when presented with complex and noisy information. However there are vast differences between biological neural networks (BNNs) of the brain and ANNs.

J R Raol is a scientist with NAL. His research interests are parameter estimation, neural networks, fuzzy systems, genetic algorithms and their applications to aerospace problems. He writes poems in English.

Sunilkumar S Mankame is a graduate research student from Regional Engineering College, Calicut working on direct neural network based adaptive control.

A thorough understanding of biologically derived NNs requires knowledge from other sciences: biology, mathematics and artificial intelligence. However to understand the basics of ANNs, a knowledge of neurobiology is not necessary. Yet, it is a good idea to understand how ANNs have been derived from real biological neural systems (see *Figures 1,2* and the accompanying boxes). The soma of the cell body receives inputs from other neurons via adaptive synaptic connections to the dendrites and when a neuron is excited, the nerve impulses from the soma are transmitted along an axon to the synapses of other neurons. The artificial neurons are called neuron cells, processing elements or nodes. They attempt to simulate the structure and function of biological (real) neurons. Artificial neural models are loosely based on biology since a complete understanding of the behaviour of real neuronal systems is lacking. The point is that only a part of the behaviour of real neurons is necessary for their information capacity. Also,

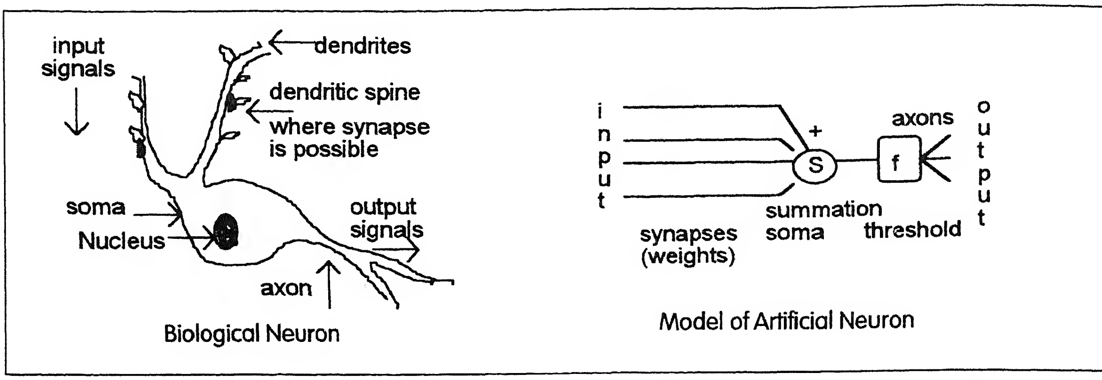


Figure 1 Biological and artificial neuron models have certain features in common. Weights in ANN model/represent synapses of BNN.

Biological Neuron System

- Dendrites input branching tree of fibres - connect to a set of other neurons-receptive surfaces for input signals
- Soma cell body - all the logical functions of the neurons are realised here
- Synapse specialized contacts on a neuron - interfaces some axons to the spines of the input dendrites - can increase/dampen the neuron excitation
- Axon nerve fibre - final output channel - signals converted into nerve pulses (spikes) to target cells

Artificial Neuron System

- Input layer the layer of nodes for data entering an ANN
- Hidden layer the layer between input and output layers
- Output layer the layer of nodes that produce the network's output responses
- Weights strength or the (gain) value of the connection between nodes

Artificial neural networks have the apparent ability to imitate the brain's activity to make decisions and draw conclusions when presented with complex and noisy information.

it is easier to implement/simulate simplified models rather than complex ones.

The first model of an elementary neuron was outlined by McCulloch and Pitts in 1943. Their model included the elements needed to perform necessary computations, but they could not

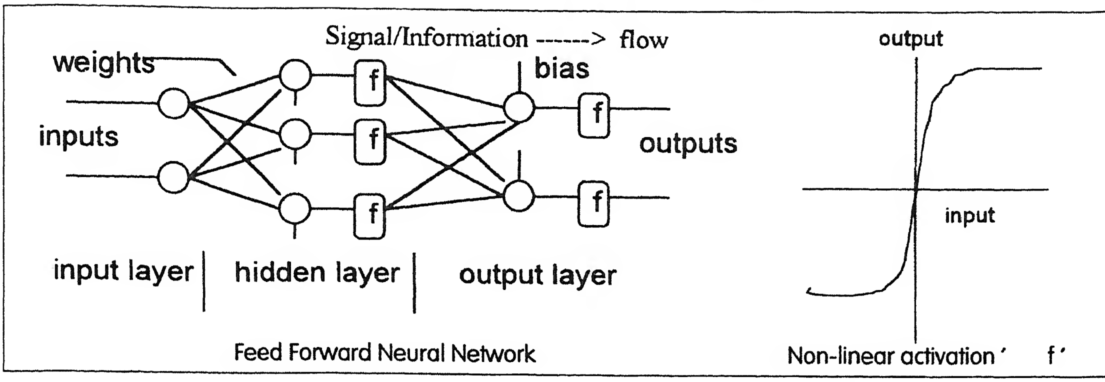


***Figure 2** A typical artificial neural network (feed forward) does not usually have feedback - flow of signal/ information is only in the forward direction. A multi-layer feed forward neural network (FFNN) is shown here. The non-linear characteristics of ANNs are due to the non-linear activation function f. This is useful for accurate modelling of non-linear systems..*

realise the model using the bulky vacuum tubes of that era. McCulloch and Pitts must nevertheless be regarded as the pioneers in the field of neural networks.

ANNs are designed to realise very specific computational tasks/ problems. They are highly interconnected, parallel computational structures with many relatively simple individual processing elements (*Figure 2*). A biological neuron either excites or inhibits all neurons to which it is connected, whereas in ANNs either excitatory or inhibitory neural connections are possible. There are many kinds of neurons in BNNs, whereas in ANNs only certain types are used. It is possible to implement and study various ANN architectures using simulations on a personal computer (PC).

Characteristics of non-linear systems

In non-linear systems, the output variables do not depend on the input variables in a linear manner. The dynamic characteristics of the system itself would depend on either one or more of the following: amplitude of the input signal, its wave form, its frequency. This is not so in the case of a linear system.

Types of ANNs

There are mainly two types of ANNs: feed forward neural networks (FFNNs) and recurrent neural networks (RNNs). In FFNN there are no feedback loops. The flow of signals/information is only in the forward direction. The behaviour of FFNN does not depend on past input. The network responds only to its present input. In RNN there are feedback loops (essentially FFNN with output fed back to input). Different types of neural network architectures are briefly described next.

- *Single-layer feed forward networks:* It has only one layer of

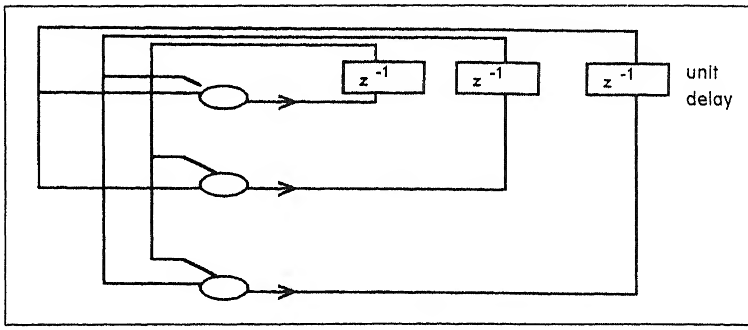


Figure 3 Recurrent neural network has feedback loops with output fed back to input.

computational nodes. It is a feed forward network since it does not have any feedback.

- *Multi-layer feed forward networks:* It is a feed forward network with one or more hidden layers. The source nodes in the input layer supply inputs to the neurons of the first hidden layer. The outputs of the first hidden layer neurons are applied as inputs to the neurons of the second hidden layer and so on (*Figure 2*). If every node in each layer of the network is connected to every other node in the adjacent forward layer, then the network is called fully connected. If however some of the links are missing, the network is said to be partially connected. Recall is instantaneous in this type of network (we will discuss this later in the section on the uses of ANNs). These networks can be used to realise complex input/output mappings.

The first model of an elementary neuron was outlined by McCulloch and Pitts in 1943. The model included the elements to perform necessary computations , but they could not realise the model using the bulky vacuum tubes of that era. McCulloch and Pitts must nevertheless be regarded as the pioneers in the field of neural networks.

- *Recurrent neural networks:* A recurrent neural network is one in which there is at least one feedback loop. There are different kinds of recurrent networks depending on the way in which the feedback is used. In a typical case it has a single layer of neurons with each neuron feeding its output signal back to the inputs of all other neurons. Other kinds of recurrent networks may have self-feedback loops and also hidden neurons (*Figure 3*).

- *Lattice networks:* A lattice network is a feed forward network with the output neurons arranged in rows and columns. It can have one-dimensional, two-dimensional or higher dimensional arrays of neurons with a corresponding set of source nodes that

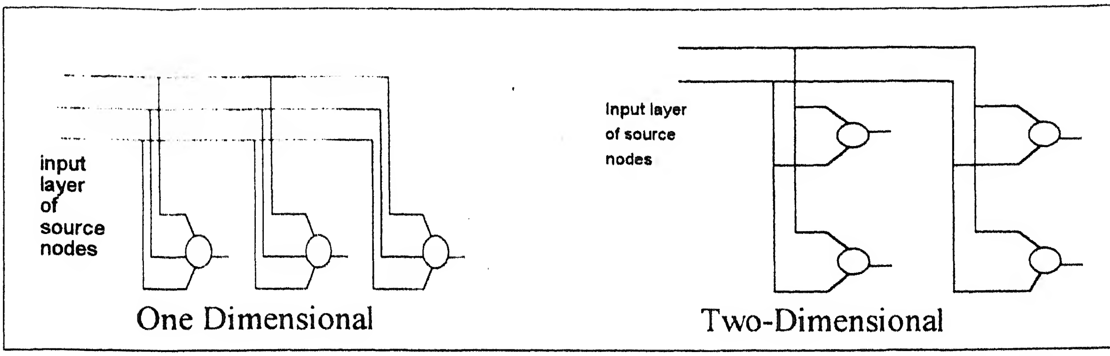


Figure 4 Lattice networks are FFNNs with output neurons arranged in rows and columns. The one-dimensional network of three neurons shown here is fed from a layer of three source nodes. The two-dimensional lattice is fed from a layer of two source nodes.

supply the input signals to the array. A one-dimensional network of three neurons fed from a layer of three source nodes and a two-dimensional lattice of 2-by-2 neurons fed from a layer of two source nodes are shown in *Figure 4*. Each source node is connected to every neuron in the lattice network.

There are also other types of ANNs: Kohonen nets, adaptive resonance theory (ART) network, radial basis function (RBF) network, etc., which we will not consider now.

Training an ANN

A learning scheme for updating a neuron's connections (weights) was proposed by Donald Hebb in 1949. A new powerful learning law called the *Widrow-Hoff learning rule* was developed by Bernard Widrow and Marcian Hoff in 1960.

How does an ANN achieve 'what it achieves'? In general, an ANN structure is trained with known samples of data. As an example, if a particular pattern is to be recognised, then the ANN is first trained with the known pattern/information (in the form of digital signals). Then the ANN is ready to recognise a similar pattern when it is presented to the network. If an ANN is trained with a character 'H' , then it must be able to recognise this character when some noisy/fuzzy H is presented to it. A Japanese optical character recognition (OCR) system has an accuracy of about 99% in recognising characters from thirteen fonts used to train the ANN. The network learns (updates its weights) from the

ANNs are used for pattern recognition, image processing, signal processing/ prediction, adaptive control and other related problems.

How does an ANN achieve 'what it achieves'? In general, an ANN structure is trained with known samples of data. For example, if a particular pattern is to be recognised, then the ANN is first trained with the known pattern/ information (in the form of digital signals). Then the ANN is ready to recognise a similar pattern when it is presented to the network.

given data while trying to minimise some cost function of the 'error' between the training set data (output) and its own output. This learning is accomplished by the popular back-propagation (BPN) algorithm, which is slow in convergence. It is a learning method in which an output error is reflected to the hidden layers (for updating the hidden layer weights). In essence, the numerical values of the weights (strengths of synapses; see the box and *Figure 2*) of the network are updated using some rule of the type:

new weights = old (previous) weights + learning rate times gradient of the cost function (with respect to the weights).

Once the ANN is trained, the 'learned information' is captured in these weights in a condensed (and yet complex) way. In general, these weights have no direct physical significance or meaning related to the process or phenomenon which is described or modelled by the ANN. However, the overall function of the ANN is relevant to a given task/application.

Although the basic processing element is simple, when several of them are connected (and also needed in many applications), the size of an ANN could be very large in terms of the number of neurons (hundreds) in a given layer. A maximum of one hidden layer is often sufficient for many tasks, to attain the required accuracy. The larger the ANN, the more time it takes to train the network. Despite the simplicity of the basic units, the mathematical theory to study and analyse the various structures and schemes based on ANNs and their (non-linear) behaviour can be very involved.

Uses of ANNs

The ANNs are used for pattern recognition, image processing, signal processing/prediction, adaptive control and other related problems. Due to the use of non-linear activation functions, the ANNs are highly suitable for very accurate mapping (modelling) of non-linear systems based on the input/output data. This non-

linear activation function is also useful in reducing the adverse effect of outliers/spikes in data, and in improving the accuracy of estimates obtained by RNN (see the box).

RNNs

RNNs are specially suitable for estimation of parameters of dynamic systems in an explicit way. The RNN-based schemes for parameter estimation have been shown (by the first author) to be the generalisation of some of the conventional parameter estimation methods. These methods are useful for estimation of parameters of dynamic systems in explicit ways, e.g. mathematical modelling of aircraft dynamics. When realised in hardware, the RNN architectures are such that they are naturally adapted to obtain fast solutions to parameter estimation problems (depending on the speed of the basic processing hardware elements). RNNs are thus specially suited for arriving at non-linear state space models of dynamic systems.

Some of the uses of ANNs (FFNNs and RNNs) are briefly mentioned here:

- Information storage/recall - The recall is a process of decoding the previously stored information by the network.
- Pattern recognition/classification - to recognise a specific pattern from a cluster of data/ to classify sets of data/information.
- Non-linear mapping between high-dimensional spaces (mathematical modelling of non-linear behaviour of systems).
- Time-series prediction (like weather forecasting), modelling of non-linear aerodynamic phenomena, detection of faults/ failures in systems like power plants and aircraft sensors.

Some of the specific applications (based on open literature)/ possibilities are:

- Assisting IC-CIM (computer integrated manufacturing of integrated circuits).
- Japanese-OCR (optical character recognition).
- Financial forecasting (the Neuro-Forecasting Centre in London).
- Process control (Fujitsu Ltd., Kawasaki, Japan).
- Analysis of medical tests.
- Target tracking and recognition (multi-sensor data fusion).

In the field of artificial intelligence, we have heard of expert systems (ES). In essence an ES is a software-based system that describes the behaviour of (human) experts in some field by capturing/collecting the knowledge in the form of rules and symbols. If fuzzy or noisy data is given to an ES, it might give wrong answers. Since the ANN-based system can be trained with some fuzzy or noisy data, the combination of ES and ANN

The days of neural network- based (parallel) computers may not be too far off. Thus brain to bread (industrial applications) neural computers will gradually become a reality.

(hybrid) might be very useful to devise powerful systems called expert networks (ENs).

Concluding Remarks

By now it must be clear that in ANNs physiological or chemical processes play no role. ANNs can be called massively parallel adaptive filters/circuits (MAPAFS). They are more like electrical/electronic (EE) circuits with some useful adaptive properties. In fact ANNs can be realised using EE hardware components. With very large scale integration (VLSI) technology, it might be feasible to fabricate microelectronic networks of high complexity for solving many optimisation and control problems using artificial neural networks. The days of neural network- based (parallel) computers may not be too far off. Thus brain to bread (-industrial applications) neural computers will gradually become a reality. As of now the field is fascinating, sometimes intriguing, and offers great challenges and promises to scientists and engineers.

Address for correspondence
J R Raol,
Flight Mechanics and Control Division,
National Aerospace Laboratories, PB 1779,
Bangalore 560017, India.

Suggested Reading

J M Zurada. Introduction to Artificial Neural Systems. West Publishing Company, New York. 1992.

S Haykin. Neural Networks - A Comprehensive Foundation. IEEE, New York. 1994.

B Kosko. Neural Networks and Fuzzy Systems - A Dynamical Systems Approach to Machine Intelligence. Prentice Hall, Englewood Cliffs, N.J. 1992.

R C Eberhart and R W Dobbins. Neural Network PC Tools - A Practical Guide. Academic Press Inc., New York. 1992.

The origin of ideas ... Ideas come when stepping onto a bus (Poincaré), attending the theatre (Wiener), walking up a mountain (Littlewood), sitting at the shore (Aleksandrov), or walking in the rain (Littlewood), but only after a long struggle of intensive work. (from *The Mathematical Intelligencer* 17(2), 1995).

On Randomness and Probability

How To Mathematically Model Uncertain Events

Rajeeva L Karandikar

Whether random phenomena exist in nature or not, it is useful to think of the notion of randomness as a mathematical model for a phenomenon whose outcome is uncertain. Such a model can be obtained by exploiting the observation that, in many phenomena, even though the outcome in any given instance is uncertain, collectively there is a pattern. An axiomatic development of such a model is given below. It is also shown that in such a set-up an interpretation of the probability of an event can be provided using the 'Law of Large Numbers'.

Rajeeva Karandikar is with Indian Statistical Institute, New Delhi. He received his Ph.D. from Indian Statistical Institute in 1982. His research interests include stochastic processes and filtering theory.

What is randomness? Do random phenomena exist outside of casinos and gambling houses? How does one interpret a statement like "*there is a 30 per cent chance of rain tonight*" — a statement we often hear on the news?

Such questions arise in the mind of every student when she/he is taught probability as part of mathematics. Many students who go on to study probability and statistics in college do not find satisfactory answers to these questions. Those who did not (and some of those who did) study probability as part of their curriculum are generally sceptical when it comes to the notions of probability and randomness. But many of them still rely on these notions — like physicists when it comes to statistical mechanics and quantum theory and engineers when it comes to communications, design of reliable systems and so on.

How does one interpret the statement that "there is a 30 per cent chance of rain tonight"?

Let us look at the question: What is a random phenomenon? Some accept that the outcome of a toss of a coin is a random event since it is not known whether the coin will come up *Heads* or *Tails*. But if one were to write down all the parameters involved, like

Some accept that the outcome of a coin toss is random since it cannot be predicted. But if one were to write down all the parameters involved, then it is conceivable that the exact path of the coin can be described by equations of motion. And if one can solve these equations, the outcome is deterministic, not random.

the exact force applied, the point where the force is applied, the wind velocity, the density of air, ... then it is conceivable that the exact behaviour of the coin can be described by equations of motion; and if one is able to solve them, the outcome can be determined. Thus it can be argued that the outcome is deterministic, not random. We may not be able to determine it easily though!

The above argument prompts us to think: *Are we calling certain events random out of sheer ignorance?*

Randomness as a Model for Uncertainty

One view which is not open to such criticism is to think of the notion of randomness as a mathematical model for events whose outcome, even in principle, is not completely specified. Immediately two questions arise. How can we model an event if its outcome is uncertain? And why should we model such events?

Think of the notion of randomness as a mathematical model for events whose outcome is not completely specified.

Let us look at the second question first. One can think of many situations where we have to make decisions under uncertainty. We need to take a train at 6.30 pm at the railway station and we need to decide when to start from home — we know that it may take anywhere between 30 minutes and 1 hour depending on the traffic; in any case before we start we don't know exactly how long it will take. Consider another situation: A drug company has come out with a drug which it claims is better than chloroquin for the treatment of malaria, and the government agency needs to decide whether to allow the company to sell the drug in the market. No one can say with certainty which medicine is more effective and what side effects the medicine may have. This is the case with most medicines. Take another situation which all of us face or have faced in the past: at the end of a school year, the teacher needs to decide which students deserve to be promoted to the next class — it is not feasible for the teacher to ask each student to do everything that has been taught in the class. We all

accept the solution in this case because we grew up with it: the teacher chooses some questions related to the material that has been taught during the year; and based on the answers to these chosen questions, the decision is made. Everyone knows that the final marks obtained by a student depend on the questions that are asked. It is possible that a question paper set by another teacher will yield a very different result. Yet, the marks obtained still give an indication of what the student has learned. We believe that it is extremely unlikely that a student who has got the highest marks in a test will fail the test if the paper were set by another teacher. One last example — the government wants to decide if enough foodgrains will be produced in the country this year or whether there will be a shortfall (in which case it has to import). In this case, as the data on food production will be available only after the harvest, when it may be too late to import, the government needs to estimate the foodgrain production and make a decision in time. The cost of an error in this case is very high for the country as we know from recent experience.

One can think of many situations where we have to make decisions based on incomplete information. So if we can mathematically model the uncertainty, it may help us in decision-making.

We can think of many more situations where we have to make decisions when we do not have complete information — may be because the event is a future event, or our understanding of the underlying phenomenon is incomplete, or it is too expensive to gather the information. Thus, if we can mathematically model the uncertainty, it may help us in decision-making.

Now let us examine the other question. How can we model uncertain events mathematically? Over the centuries, mankind has observed many phenomena in which the outcome in any given instance is uncertain, but collectively the outcomes conforms to a pattern.

Over the centuries, mankind has observed many phenomena where the outcome in any given instance is uncertain; but collectively it conforms to a pattern. We cannot say whether a particular unborn baby will be a boy or a girl, but the number of male and female children born worldwide is always almost the same.

An example of this is: Though, to start with, one could not tell whether an unborn child would be a boy or a girl, the total number of births in a town over a year showed a pattern — the number of male children and female children were approximately the same.

And this was observed in different towns, across the continents. The situation has changed marginally. Today, by medical tests, it can be determined a few months before birth if the unborn child is a boy or a girl; but even today, there is no deterministic model which can tell us the sex of an unborn child at the moment of conception.

The next example is from physics — about radioactive substances. It is known that certain substances like radium and uranium spontaneously emit particles like alpha and beta particles and/or electromagnetic radiation like gamma rays. This phenomenon is called 'radioactive decay'. This happens because some of the nuclei (i.e. radioactive nuclei) of such substances are unstable. It is also observed that the rate of this decay is proportional to the number of radioactive nuclei present in the substance, and does not depend on other factors such as the shape of the substance and other physical conditions of the environment. In fact it has been observed that the number of radioactive nuclei present in a sample of a radioactive substance is reduced to half the initial number in a fixed length of time. This time is called the *half life*. We seem to know exactly what will happen if we have, say, 1 gram of radioactive material. Yet there is no (deterministic) model at the atomic level for determining when a specified atom will disintegrate.

We seem to know exactly what will happen if we have a gram of radioactive material. Yet there is no deterministic model at the atomic level to predict when a specified atom will disintegrate.

Similar is the case with the kinetic theory of gases. It deals with the collective behaviour of gas molecules, but there is no deterministic model for the behaviour of an individual gas molecule. There are many such instances in physics.

The Model

Let us assign to an uncertain event a number between 0 and 1 which we call its *probability of occurrence* with the understanding that higher the number, the higher is the chance that it will occur. Also, let us postulate that the *certain* event (i.e. an event that will

definitely happen) has probability 1 and the *null* event (i.e. an event that will never occur) has probability 0. We also postulate that if two events cannot occur simultaneously (such events are called mutually exclusive), then the probability that one of the two events will occur is the sum of their respective probabilities.

Let us consider experiments that can result only in one of countably many outcomes (finite or infinite) — we exclude, for now, experiments which can result in one of uncountably many outcomes. Let us represent the outcomes as ω_i and let

An infinite set can be *countable*: e.g. the set {1, 2, ... *n*, ...} or *uncountable*: e.g. the set of all points on the unit interval (0, 1).

$$\Omega = \{\omega_1, \omega_2, \omega_3, \cdots, \omega_N\}$$

if the total number of outcomes is $N < \infty$ or

$$\Omega = \{\omega_1, \omega_2, \omega_3, \cdots, \omega_n, \cdots\}$$

if the total number of outcomes is countably infinite.

The probability of occurrence of an event is a number between 0 and 1. The higher the number, the higher is the chance that the event will occur.

Subsets of Ω are called events. We say that the event A has occurred if the experiment results in an outcome $\omega_i \in A$. A probability allocation for this experiment is given by a real-valued function P defined on the set of all subsets of Ω such that

$$0 \le P(A) \le 1 \qquad \forall A \subseteq \Omega.$$

Further, if A, B are mutually exclusive (i.e. $A \cap B = \Phi$), then

$$P(A \cup B) = P(A) + P(B). \tag{1}$$

Let p_i be the probability of occurrence of the event $\{\omega_i\}$; i.e. $p_i = P(\{\omega_i\})$. Then the postulates stated above imply that :

1. $p_i \ge 0 \qquad \forall i$
2. $\sum_{i:\omega_i \in \Omega} p_i = 1$
3. $P(A) = \sum_{i:\omega_i \in \Omega} p_i, \quad \forall A \subseteq \Omega.$

Thus once we choose $p_i = P(\omega_i)$, the probabilities of all events $A \subseteq \Omega$ are determined. How does one go about choosing p_i?

Well, this is where the *modelling* aspect comes into the picture. The p_i's of the probability model should reflect all the information we have on the phenomenon or should at least be a close approximation of the same. We will begin with the simplest situation and draw conclusions in this case. We will get an interpretation for the numerical value of the assigned probability of an event and this in turn will help us in modelling more complicated phenomena.

The probability model used should reflect all the information available on the phenomenon.

Let us now consider the situation where Ω is a finite set with $\Omega = \omega_1, \omega_2, \omega_3, \cdots, \omega_N$, and where given all the information about the phenomenon, we have reason to believe that all outcomes are *equally likely*. In this case, the appropriate choice of probabilities is

$$P(\omega_i) = \frac{1}{N} \quad \forall i \in \Omega.$$

This is clearly the case when there is an inherent symmetry in the phenomenon; for example, most of us will agree that "the *chance* that the first child born in a given nursing home the next day is a boy" is the same as "the chance that the child will be a girl". Thus the events ω_1 = *the child is a boy* and the event ω_2 = *the child is a girl* are equally likely, and we can model the probabilities for this experiment as

$$P(\omega_1) = \frac{1}{2}, \quad P(\omega_2) = \frac{1}{2}.$$

Similarly, if we are told that a family has 3 children but we have no further information, we are justified in postulating that all the 8 possibilities *GGG, GGB, GBG, GBB, BGG, BGB, BBG, BBB* are equally likely and hence the probability of each of these events is $1/8$. This is based on the observation that knowing that the first

child is a girl (or a boy) does not give any information about the sex of the next child.

Let us look at the following experiment. Consider an urn containing 12 balls of the same size and weight, numbered 1 to 12. Suppose that the balls with numbers 1, 2 and 3 are red balls, and the rest are blue. If the balls in the urn are mixed well and one ball out of them is drawn without looking at the colour/number, then the 12 events (that the ball with number i on it is drawn, $1 \leq i \leq 12$) can be modelled as equally likely — each with probability $1/12$. As a result the probability that the ball so drawn is red is $1/4$. Now even if the balls are not numbered, but the urn contains 3 red and 9 blue balls, then the probability of drawing a red ball is still $1/4$. Thus even if the balls are not numbered, we can always pretend that they are numbered.

We can thus draw the following conclusion: if a given experiment can result in N outcomes, and based on all the information that we have on the phenomenon, they seem to be equally likely, and if a given event occurs in M out of the N outcomes, then its probability (corresponding to the model that the N outcomes are equally likely) is M/N. Note that we are not adopting this as a definition, but as a model for the phenomenon. If another person has more information on the experiment, his model, i.e. allocation of probabilities, could be quite different.

If a given experiment can result in N equally likely outcomes and a given event occurs in M out of N outcomes, then its probability of occurrence can be modelled to be M/N.

Now let us consider two urns, both like the one considered above. The experiment consists of drawing one ball from each of the urns. This time, all the $12 \times 12 = 144$ outcomes are equally likely. Out of these, $3 \times 3 = 9$ outcomes determine the event that both the balls drawn are red, and hence its probability is $9/144 = 1/16$. Note that this is equal to the product of the probabilities of the event that the first ball is red and of the event that the second ball is red. Here we are in a situation where the two events are independent — *i.e. the occurrence or otherwise of the first event does not change our perception of the second event.* In such a situation, the

events are said to be independent and the probability that both events occur can be taken to be the product of the two events. This is a very important notion and very useful in model building.

Consider two experiments,

$$\Omega_1 = \{\omega_i^{(1)} : i \in I^{(1)}\} \text{ and } \Omega_2 = \{\omega_j^{(2)} : j \in I^{(2)}\}$$

$I^{(1)}, I^{(2)} \subseteq N$, and suppose that we have a model for each of them, namely

If two events are independent, the occurrence or otherwise of the first event does not change our perception of the second event. The probability that both events occur can therefore be taken to be the product of the individual probabilities of the two events.

$$P(\{\omega_i^{(1)}\}) = p_i^{(1)} \text{ and } P(\{\omega_j^{(2)}\}) = p_j^{(2)} .$$

The set of possible outcomes for the *joint* experiment is

$$\Omega = \{(\omega_i^{(1)}, \omega_j^{(2)}) : i \in I^{(1)}, j \in I^{(2)}\}.$$

If the experiments are such that the outcome of one has no bearing on the outcome of the other, then it is reasonable to model the joint experiment as follows :

$$P(\{\omega_i^{(1)}, \omega_j^{(2)})\}) = p_i^{(1)} p_j^{(2)}.$$

Similarly, if we have a model for each of finitely many experiments and if these experiments are independent of each other, then we can construct a model for the experiment which consists of performing all these experiments together.

Now we are in a position to provide an interpretation for the probability of an event related to an experiment. We shall show that if this experiment can be repeated again and again (independently) then the limit of the proportion of occurrences of this event is exactly its probability.

Law of Large Numbers

Let us now fix a set of outcomes, $\Omega = \{\omega_i : i \in I\}$, $\omega_i \neq \omega_j$ for $i \neq j$ where $I = \{1, 2, 3, \ldots, N\}$ or $I = \{1, 2, 3, \ldots ,N, \ldots\}$. Also let

us fix an assignment of probabilities for subsets of Ω. Recall that such an assignment is determined by

$$p_i = P(\{\omega_i\})$$

and then for any *event* A,

$$P(A) = \sum_{i:\, \omega_i \in A} p_i$$

A function X from Ω into $\boldsymbol{R}$ is called a *random variable.* We think of X as follows : X represents a certain numerical characteristic of the outcome of the experiment, and after the experiment is conducted we get to observe the function X at the outcome (we may or may not actually observe the outcome).

A random variable represents a certain (measurable) characteristic of the outcome of the experiment.

Let X be a random variable and let f be a function from the real line into itself. We denote by $f(X)$ the random variable given by

$$f(X)(\omega_i) = f(X(\omega_i)).$$

Also, let $R(X)$ denote the range of X i.e. $R(X) = \{x \in \mathrm{R}$: there exists $\omega \in \Omega$ with $X(\omega) = x\}$. For a subset A of $\boldsymbol{R}$, we will write $X \in A$ for the set $\{\omega_i: X(\omega_i) \in A\}$. When $A = \{x\}$ we will also write $X = x$ for $X \in A$. The function $x \rightarrow P(X = x)$ is called the distribution of X. It is easy to check that

$$P(\{X \in A\}) = \sum_{x \in A} P(\{X = x\}).$$

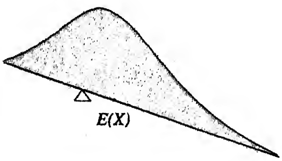
A random variable X is said to be bounded if there exists a finite constant K such that

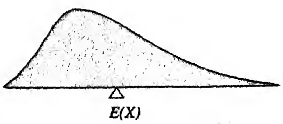
$$P(-K \leq X \leq K) = 1.$$

For a bounded random variable X, we define its *expected* value $E(X)$ by

$$E(X) = \sum_{i \in I} X(\omega_i)\, p_i. \tag{2}$$

Expectation and Variance





Think of the expected value as the centre of gravity of the probability distribution. Imagine placing mass $P(\{X=x\})$ at the point x (for each x) on a beam; the balance point of the beam is the expected value of X.

The variance of a probability distribution indicates how dispersed the distribution is about its centre of gravity or how spread out on the average are the values of the random variable about its expected value.

E(X) represents the quantity we expect to observe on the average, if we repeat the experiment (independently) a large number of times. Hence the name *expected value*. A justification of the statement made above is given towards the end of this article.

Let us observe that for a random variable X,

$$E(X) = \sum_{x \in R(X)} x\, P(\{X = x\}). \tag{3}$$

To see this, let $A_x = \{\omega_i : X(\omega_i) = x\}$. Then

$$\begin{aligned} E(X) &= \sum_{i \in I} X(\omega_i)\, p_i \\ &= \sum_{x \in R(X)} \sum_{\omega_i \in A_x} x\, P(\{\omega_i\}) \\ &= \sum_{x \in R(X)} x\, P(\{X = x\}). \end{aligned}$$

For a bounded random variable X such that $E(|X|^2) < \infty$, let us define the *variance* of X by

$$\mathrm{Var}(X) = E(X-\mu)^2$$

where $\mu = E(X)$.

Let us note that for a positive random variable Y,

$$\begin{aligned} \lambda P(\{Y \geq \lambda\}) &= \lambda \sum_{y \in R(Y) : y \geq \lambda} P(\{Y = y\}) \\ &\leq \sum_{y \in R(Y) : y \geq \lambda} y P(\{Y = y\}) \\ &\leq \sum_{y \in R(Y)} y P(\{Y = y\}) \\ &= E(Y), \end{aligned}$$

and as a consequence, one has (for positive random variables Y)

$$P(Y \geq \lambda) \leq \frac{1}{\lambda} E(Y). \tag{4}$$

Using this for $Y = (X - \mu)^2$ (where $\mu = E(X)$), one has

$$P(\{|X - \mu| \geq t\}) \leq \frac{1}{t^2} \operatorname{Var}(X). \tag{5}$$

This inequality is known as *Chebychev's inequality.*

Chebychev's Inequality gives a bound on the probability of the tails of a distribution.

Independence

We say that two events A, B are independent if

$$P(A \cap B) = P(A)\, P(B).$$

A collection of random variables $X_1, X_2, \cdots, X_n$ is said to be a collection of independent random variables if

$$P(\cap_{j=1}^{n} \{X_j = x_j\}) = P(\{X_1 = x_1\})\, P(\{X_2 = x_2\}) \cdots P(\{X_n = x_n\})$$

for all $x_j \in R(X_j)$: $1 \leq j \leq n$.

Lemma 1: Let X,Y be independent random variables. Let f, g be bounded functions on the real line. Then

$$E(f(X)\, g(Y)) = E(f(X))\, E(g(Y)).$$

Proof : First consider the case when both f, g are positive functions. Then it can be checked that

$$E(f(X)\, g(Y)) = \sum_{x \in R(X),\, y \in R(Y)} f(x)\, g(y)\, P(\{X = x, Y = y\}).$$

Using independence of X,Y, it follows that

$$E(f(X)g(Y)) = \sum_{x \in R(X), y \in R(Y)} f(x)g(y)P(\{X=x\}), P(\{Y=y\}).$$

The required identity now follows from this.

Theorem 2: Let X,Y be bounded independent random variables. Then

$$\text{Var}(X+Y) = \text{Var}(X) + \text{Var}(Y).$$

The essential content of the Weak Law of Large Numbers is that if our experiment can be repeated again and again, independently, then the limit of the proportion of occurrences of this event is exactly its probability!

Proof: Let $\mu = E(X)$, $\nu = E(Y)$, $U = X - \mu$, $V = Y - \nu$. It is easy to see that $\text{Var}(X) = \text{Var}(U)$, $\text{Var}(Y) = \text{Var}(V)$, $\text{Var}(X + Y) = \text{Var}(U + V)$. Also, $E(U) = E(V) = 0$. Thus

$$\begin{aligned} \text{Var}(U+V) &= E((U+V)^2) \\ &= E(U^2) + E(V^2) + 2E(UV) \\ &= \text{Var(U)} + \text{Var(V)} \end{aligned}$$

where we have used the previous lemma in deducing that $E(UV) = 0$. The required result now follows from this.

We are now in a position to prove the *Weak Law of Large Numbers*.

Theorem 3: Let $X_1, X_2, \cdots, X_n \cdots$ be a sequence of bounded random variables such that for each n, $X_1, X_2, \cdots, X_n$ is a collection of independent random variables and such that for all $i \geq 1$, $R(X_i) = R(X_1)$ and

$$P(\{X_i = x\}) = P(\{X_1 = x\}) \qquad \forall x \in R(X_1).$$

There is also the *Strong Law of Large Numbers* which deals with a different and actually stronger mode of convergence of Z_n, the proof of which is, however, beyond the scope of this article.

Let $\mu = E(X_1)$ and let $Z_n = \frac{1}{n}\sum_{i=1}^{n} X_i$. Then for all $\varepsilon > 0$,

$$\lim_{n \to \infty} P(\{|Z_n - \mu| > \varepsilon\}) = 0.$$

Proof : Using Theorem 2, it follows that

$$\mathrm{Var}\,(Z_n) = \frac{1}{n^2}\left\{\sum_{i=1}^{n} \mathrm{Var}\,(X_i)\right\}$$

$$= \frac{1}{n^2}\, n\, \{\mathrm{Var}\,(X_1)\}$$

$$= \frac{1}{n}\, \{\mathrm{Var}\,(X_1)\}$$

Now using the inequality 5, we obtain for $\varepsilon > 0$

$$P(\{|Z_n - \mu| > \varepsilon\}) \leq \frac{1}{\varepsilon^2}\frac{1}{n}\, \mathrm{Var}\,(X_1).$$

The required conclusion follows from this.

Interpretation of Probability of an Event

Let us consider an experiment with the space of outcomes $\Omega = \{\omega_i\colon i \in I\}$ and with assignment of probabilities $P(\{\omega_i\}) = p_i$. (Here, I is either equal to $\{1,2, \cdots ,N\}$ or is the set of natural numbers.)Let us fix an *event* A (i.e. a subset of Ω) with $P(A) = \theta$.

Let us consider repeating the experiment n times, in such a way that the outcome of the previous trials has no influence on the next trial. This time the set of outcomes of this repeated experiment can be taken to be

$$\Omega^n = \{(\omega_{i_1}, \omega_{i_2}, \omega_{i_3}, \cdots, \omega_{i_n}) : i_1, i_2, \cdots, i_n \in I\}.$$

Since we have assumed that the experiments have been performed independently of each other, we are justified in assigning the probabilities as follows:

$$P(\{(\omega_{i_1}, \omega_{i_2}, \omega_{i_3}, \cdots, \omega_{i_n})\}) = p_{i_1}\, p_{i_2} \cdots p_{i_n}.$$

Suggested Reading

W Feller. An Introduction to Probability Theory and Its Applications. Vol. 1. (Third Edition). Wiley-Eastern, New Delhi. 1985.

P G Hoel, S C Port and C J Stone. Introduction to Probability Theory. Universal Book Stall, New Delhi. 1991.

K L Chung. Elementary Probability Theory and Stochastic Processes. Narosa Publishing House, New Delhi. 1978.

The statement that "there is a 30 per cent chance of rain tonight" simply means that under a given weather forecasting probability model, the probability of the event that it will rain tonight is 0.3.

Let us define random variables $X_1, X_2, \cdots X_n$ as follows:

$$X_i((\omega_{i_1}, \omega_{i_2}, \omega_{i_3}, \cdots, \omega_{i_n})) = 1_A(\omega_i)$$

where 1_A denotes the indicator function of the set A i.e. $1_A(\omega_i) = 1$ if $\omega_i \in A$ and $1_A(\omega_i) = 0$ if $\omega_i \notin A$. Then it follows that $X_1, X_2, \ldots, X_n$ satisfy the conditions of Theorem 3 with $E(X_1) = \theta$. It thus follows that given $\varepsilon > 0, \eta > 0$, we can choose n_0 such that for $n \geq n_0$, one has

$$P(|\frac{1}{n}(X_1 + X_2 + \cdots + X_n) - \theta| > \varepsilon) \leq \eta.$$

Let us note that $(X_1 + X_2 + \cdots + X_n)/n$ is the proportion of the times the event A occurred in the n independent repetitions of the experiment. We have seen above that for large n, this observed proportion is close to the probability of A.

This gives us an interpretation of $P(A)$. Similarly, we can get an interpretation for $E(X)$—namely, if we repeat the experiment a large number of times and compute the average of the observed values of X, then, with a high probability, this average is close to the expected value $E(X)$ of X.

Let us briefly return to the question posed at the beginning of the article: how does one interpret a statement like *there is a 30 per cent chance of rain tonight*?

From some theoretical reasoning and some observational data, weather forecasters (and other forecasters) usually have probability models for forecasting. The above statement simply means that under such a model, the probability of the event that it will rain tonight is 0.3.

Address for correspondence
Rajeeva L Karandikar,
Statistics and Mathematics Unit,
Indian Statistical Institute,
7 S J S Sansanwal Marg
New Delhi 110 016, India.

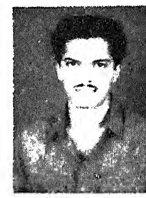
Niels Bohr said ... "It is difficult to predict, especially about the future".

What's New in Computers

The CD-ROM

Vijnan Shastri

This article describes the CD-ROM; information storage and retrieval, cost and new applications for the future.



Vijnan Shastri works at the Centre for Electronics Design Technology in the Indian Institute of Science, Bangalore, and his areas of interest are digital and microprocessor systems, storage subsystems and systems software.

Introduction

You have probably heard of the compact disc read-only memory (CD-ROM) and wondered if it related to the compact disc (CD) that is widely used in music systems. You're right - it *is* related. But how is it used in computers? Is it identical to the CD-audio ? What are its advantages? If it is memory then how much can it store? In the following paragraphs this article answers these and other questions about the CD-ROM and its use as a storage medium for data.

The CD-ROM, like the CD-audio disc, is made of polycarbonate and is 5.25 inches in diameter. Both have a spiral track moving outward from the centre to the periphery where data is digitized and stored. In the case of CD-audio, it is only sound which is digitized and stored whereas in the CD-ROM it is data. This data can be text, still pictures (digitized) or video data (also digitized), audio or a combination of all of them. Digitization of data is the key factor in storing them; which is done as files (unlike CD-audio). Such a file system is needed to organize, store and access the data. The design and format of the file system on a CD-ROM has been standardized by the International Standards Organization and is known as the ISO9660 file system standards.

The design and format of the file system on a CD-ROM has been standardized by the International Standards Organization and is known as the ISO9660 file system standards.

Pits and Lands

The digitized data (which means that the data is encoded in terms of 1s and 0s) is stored as 'pits' and 'lands' at the bottom surface of

The digitized data (which means that the data is encoded in terms of 1s and 0s) is stored as 'pits' and 'lands' at the bottom surface of the CD-ROM platter.

the CD-ROM platter (See *Figure 1*). The lands reflect the light from the laser beam and the pits scatter the beam. The optical head consists of a complex arrangement of lenses, prisms and photodiodes (to detect the light reflections). The optical head arrangement is the same in both the CD-audio and CD-ROM drives. The transition from land to pit or pit to land is coded as '1' and the lack of transition is coded as '0'. The diameter of the laser beam (red laser) is about 670 nano meters. The spiral track is 0.6 micrometer wide with a width of 1 micrometer between spirals. As can be seen in the figure, the layered covering ensures that the life of the CD-ROM is about 100 years (provided it is not badly damaged). The data encoding incorporates a lot of error detection coding (EDC)

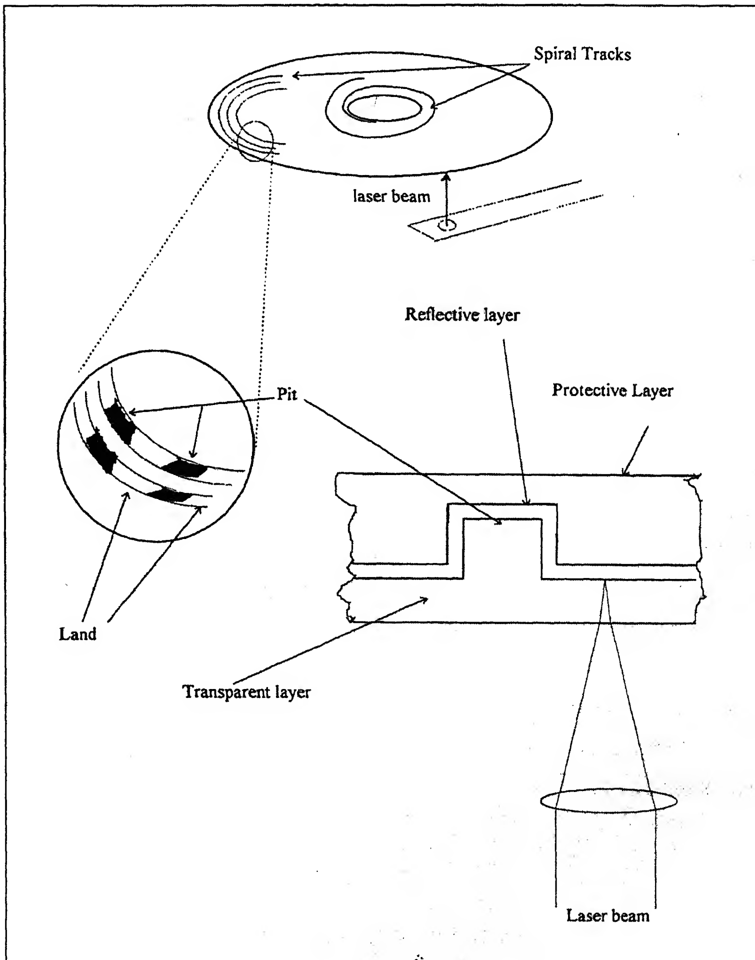


Figure 1 CD-ROM schematic.

and error correction coding (ECC) such that even if there are dust particles or minor scratches, the data can be read off the disc as if these didn't exist.

About 200,000 pages of the type which you are now reading can be stored on a CD-ROM.

The CLV scheme

The CD-ROM is itself mounted on a 'turn table' that is driven by a DC servo motor. The important point to note here is that the density of data stored (i.e., of pits and lands per unit length) is constant throughout the spiral. This implies that in order to obtain a constant read -out rate the disk must rotate faster for the tracks near the centre and slower at the outer tracks so as to maintain a constant linear velocity (CLV) between the head and the CD-ROM platter. This is in contrast to magnetic discs which are of the constant angular velocity (CAV) type. In that case the density of data varies: it is more near the centre and less as the head moves outward (again to maintain a constant read -out rate). Research has shown that one can store about twice as much in a CLV type of scheme as compared to a CAV scheme. How much is this data? It is totally 660 Mbytes! This means that about 200,000 pages of the type which you are now reading can be stored on a CD-ROM. The optical head moves radially and the servo motor must re-adjust the rotational speed every time the head moves. The optical head must 'lock' onto the correct part of the spiral once it has moved. Thus the motor control system is a complex one since it has to also respond quickly.

Speed of CD-ROM drives

The success of the CD-audio paved the way for the usage of the CD-ROM in the computer industry for archival storage. Thus until about 1992, the CD-audio drive and the CD-ROM drive had the same motor electronics (and optics) and hence had the same speeds. These were called single-speed drives. Their speed varied from about 300 rpm in the inner tracks to about 500 rpm on the outer tracks. These drives retrieved data at about 150 kbytes/second. Subsequently these single speed drives (although widely

In this multimedia age we need high speed CD-ROM drives to playback video smoothly without jerky movements.

It is not just the data storage capacity of CD-ROMs that is important. This capacity, coupled with the ability of powerful retrieval software running on desktop machines makes the CD-ROM an extremely powerful data storage medium

used) gave way to double-speed (300 kbytes per second), quad-speed (600 kbytes per second) and now 6X speed (900 kbytes second) drives. These retrieval rates are not required for text-only information. But in this multimedia age with information consisting of moving pictures and sound, these data rates are required to playback video smoothly, without jerky movements.

Applications of CD-ROM

Initially CD-ROMs were used for archival storage of text information and text databases. It must be realized that it is not just the data storage capacity of CD-ROMs that is important. This capacity, *coupled with the ability of powerful retrieval software running on desktop machines makes it an extremely powerful data storage medium.* Nowadays they have become popular as distribution media for software as the size of software becomes unwieldy for storage on floppies. However, multimedia capability of desktop PCs has meant that the CD-ROM is the medium of choice to store multimedia data and has spawned a whole gamut of applications. These include multimedia encyclopaedias, multimedia magazines (which the user receives monthly), education aids, and of course multimedia-interactive games. The latter has been enormously successful and is partly responsible for bringing the computer on a large scale into homes of large numbers of people who would not otherwise have bought one.

How much does it cost?

The cost of 'mastering' (manufacturing) a CD is now well below a dollar. One pays for the *data* on the platter, not for the platter itself!

Due to improved manufacturing and mass production concepts the cost of 'mastering' (manufacturing) a CD is well below a dollar. One pays not for the CD-ROM platter but for the data on that platter. Recently, availability of small equipment enabling the production of CD-ROMs without a complex manufacturing setup has brought CD-ROM -based publishing to the desks of a large number of medium and small publishers. This is made possible with the availability of the write-once read-only memory (WORM) discs. The only difference between the CD-ROM and WORM is

that CD-ROMs need to be mastered in a manufacturing process whereas WORM discs can be written (albeit only once) like magnetic discs.

Future of the CD-ROM

The CD-ROM has proliferated and has become an integral part of storage hardware, operating in conjunction with magnetic discs, and tapes. The use of more than one layer on a single platter and the development of the blue laser (with a wavelength of 430 nano meters) will mean that CD-ROM capacities will increase to about 3 gigabytes by mid 1997. This storage capacity will mean that it will be possible to store entire full-length movies (at high resolution) on a single CD-ROM and this will naturally spur a host of new applications — especially in the consumer market. With the development of efficient archiving software, libraries of the future will store most of the information on CD-ROM (hopefully helping to save a bit of paper). Users will be able to quickly search, retrieve and perhaps download information they need on their local computers. Remember that this information will include not only text but also sound and moving images. A user wanting to learn about the history of the temples of India will not only be able to read the history, but he/she will also be able to see images of these temples and hear historians talk about them.

CD-ROM capacities will increase to about 3 gigabytes by mid 1997. So a user wanting to learn about the history of indian temples will not only be able to read the history, but also see images of the temples and hear historians talk about them.

Address for correspondence
Vijnan Shastri
Centre for Electronics Design Technology,
Indian Institute of Science,
Bangalore 560 012, India.

Francis Crick wrote ... (In *What Mad Pursuit*): "Had Jim (Watson) and I not succeeded, I doubt whether the discovery of the double helix could have been delayed for more than 2 or 3 years .... In some ways the code embodies the core of molecular biology, just as the periodic table of the elements embodies the core of chemistry, but there is a profound difference — the periodic table is probably true."

Nature Watch

The Dhole or the Asiatic Wild Dog

Arun Venkataraman

Arun Venkataraman has used the finest techniques of modern behavioural ecology to investigate the ecology and sociobiology of social wasps on the one hand and wild dogs on the other. He enjoys combining these basic research programmes with his responsibility as Conservation Biologist at the Asian Elephant Conservation Centre.

The dhole *(Cuon alpinus)* is a social hunter and a cooperative breeder. Dholes live in packs with rigid hierarchies. Their social behaviour, hunting strategies and breeding patterns are described in this article.

On the Dhole Trail

It was a hot sultry morning, punctuated by the incessant calls of cicadas. I was deeply engrossed in following our study pack of dholes travelling in single file up a forest road in Kargudi, a prime dhole habitat in the Mudumalai sanctuary, Tamil Nadu, South India. The sanctuary forms a part of the Nilgiri biosphere reserve, straddling an area of approximately 5000 sq km in the three southern states of Kerala, Karnataka and Tamil Nadu. The pack consisting of 10 dholes had not killed any prey that morning. It was unusual that they were still moving as they usually give up hunting by this time, preferring to spend the hottest portion of the day resting and eagerly anticipating the evening hunt. A small, sudden burst of activity ensued and three dholes lagging behind the rest of the pack dived into bushes on the roadside. Two of them reappeared almost immediately. The third one eventually emerged holding a quivering mouse deer (*Tragulus memmina*), Asia's smallest deer, in it's mouth. Casting what I imagined to be furtive glances towards the pack, it disappeared into the bushes and with loud crunching sounds, ate the entire animal in seclusion. After this solitary meal it proceeded to join the pack. The pack individuals on sensing its arrival bounded towards the errant animal, probably aroused by the smell of flesh and blood emanating from the recent meal. Mild aggression was displayed towards this animal and the pack proceeded along its way as if nothing had happened.

The dhole is a rufous coloured animal with a beautiful plume-like black tail.

Dhole Habitats

The above incident relates what constitutes rather contrasting selfish behaviour in an otherwise highly social animal. Dholes display a high level of sociality. This is in stark contrast to the solitary leopard (*Panthera pardus*) and tiger (*Panthera tigris*), the two other large carnivores that often share habitats with dholes. The dhole or the Asiatic wild dog (*Cuon alpinus*) is a social canid (animals which belong to the dog family) that inhabits most forested areas of south, south-east and continental Asia. Once distributed as far as eastern Europe, its range has been drastically diminished due to direct persecution by man and loss of habitat. In India, dholes were once widespread throughout the country. The Terai region (foothills of the Himalayas) of North India, which still retains excellent dhole habitats once contained a high population of dholes. Dholes are as good as extinct in this area today. They exist only in small pockets of forest in the north-east Indian hills, in the states of Assam and Meghalaya. The best populations exist in Myanmar and central and southern India. Ample prey in the dry deciduous tracts of forest are partially responsible for their relative security in these areas. Human pressures on habitat and wanton hunting of prey species have virtually exterminated dholes from most parts of south-east Asia. In many areas it has traditionally and erroneously been classified as vermin, thought to deplete natural populations of wild ungulates as well as kill domestic cattle. Systematic bounty hunting and poisoning has caused its extinction over much of its range, especially in Central Asia.

Dholes display a high level of sociality. This is in stark contrast to the solitary leopard and tiger, the two other large carnivores that often share habitats with dholes.

Social Behaviour

The dhole is a rufous coloured animal with a beautiful plume-like black tail which is effectively used for signalling the status of an animal in the dominance hierarchy. Dominance hierarchies are rigid with an alpha male and female at the top of the hierarchy. Dominant animals participate in much of the breeding and

Dominance hierarchies are rigid with an alpha male and female at the top of the hierarchy.

Dholes often live in aggregations of individuals called packs.

possibly also social decision-making. Rather stockily built, males and females weigh around 15 and 13 kgs respectively. It is a compact, lethal hunter well adapted for coursing at high speeds in pursuit of prey. It differs from the genus *Canis* (wolves, jackals, domestic dogs and coyotes) by having two molars instead of three, and many more teats.

Dholes often live in aggregations of individuals called packs. Such packs are highly structured and individuals within them coordinate activities such as hunting and breeding. Pack members coordinate while pulling down and killing large prey such as adult sambar (*Cervus unicolor*) and chital (*Axis axis*). Individuals may grab the ear, tail and other parts of the body, eventually weighing down the animal before actually killing it. Although the meat is generally shared, there is some squabbling among individuals with dominant individuals cornering the choicest bits of meat. Young pups within the packs are allowed to have precedence over others while feeding. Dhole packs, however, usually kill smaller animals such as sambar and chital fawns. Most pack members help in surrounding small prey and block their escape while the older males move in for the kill. Older females and younger animals usually tend to lag behind and join in for the feeding. Dholes usually kill once a day, but on many a day hunting proves unsuccessful or the animal killed is too small to ensure a full belly to all pack members.


MILIND WAT

Figure 1 At the den: A helper with 6 pups visible. A total of 8 pups were born in this pack during December 1990.

Following mating in October, pups are born in December within an earthen den, which is usually a complex of inter-connected tunnels in a dry river bank (see *Figure 1*). They spend around 3-4 weeks in such dens and the pack eventually moves them to another type of den, usually a hole or a cave under an out-crop of rocks. In front of such dens is a play area, where the pups play, spar with each other, begin establishing dominance hierarchies and through such behaviour hone their deadly hunting skills. I have seen three pups stand flank to flank and pick up a stick together with perfect coordination. Does this kind of behaviour ensure the high degree of coordination necessary for hunting? In addition to

milk from their mother, they also receive regurgitated food from other pack members. Pack members play with pups, groom and guard them and keep a watch over their early forays from the den. When the pups are two months old they start receiving solid food. It is around this time that they begin getting restless and make longer trips away from the den, rushing back at the slightest hint of danger. The packs also change dens quite frequently and have been seen to change as many as five dens in an area of one square kilometre. It is possible that they do this to deter predators such as leopards and hyenas who may find the den and lift the pups. Smell from uneaten food, pup and adult odours and faeces make the den easy to detect, forcing packs to change them regularly.

I have seen three pups standing flank to flank, pick up a stick together with perfect coordination. Does this kind of behaviour ensure the high degree of coordination necessary for hunting?

Mating Practices

On most occasions only a single female litters, despite the presence of other sexually mature females. We have even noticed subordinate females disappearing during the mating season possibly as a result of behavioural antagonism from the dominant female. It would be interesting to determine what happens to these breeding females. Do they actually team up with solitary males from other packs, litter and form new packs or do they join already established packs? Similarly, we do not know what happens to males who leave packs. Some lone males leave their natal pack for short periods and later rejoin the pack. During their absence from their natal pack, they may be assessing their chances of gaining access to lone females and forming other new packs. There is evidence to suggest that males tend to leave packs along with other males who are possibly their brothers and join packs where the dominant male has just died or left. Even though only one of the males assumes the role of dominant male of the pack, all other males including those who are unrelated to the pack members, display a great deal of helping behaviour, towards the pack's young. We have noticed solitary males following established packs during the mating season. Are these males actually trying to gain access to pack females or are they anticipating the

The packs frequently change dens; I have seen as many as five dens in an area of one square kilometre. It is possible that they do this to deter predators such as leopards and hyenas who may find the den and lift the pups.

The hunting strategy requires a very specific distribution of prey which in turn requires a unique habitat. One can envisage that such a delicate system is constantly under threat due to human population pressures on valuable forest land.

departure of subordinate sexually mature females from the pack? Many of the above questions, though extremely important, remain unanswered. Intense and painstaking monitoring of pack members, spanning many years, may shed some light on these fascinating issues.

Hunting Strategies

The main prey of dhole packs in the Mudumalai sanctuary are chital, which live in herds. Some forested areas contain many herds while others don't contain any. This kind of distribution is called a patchy one. At least one dhole pack hunts within a single patch for a few days and when their hunting stops yielding adequate gains, they switch to a fresh patch and repeat the process. This strategic hunting may ensure steady long-term gains in terms of chital killed. In addition to strategic use of their home ranges, dholes may have extremely elaborate methods for hunting prey. I have often seen some dhole pack members jumping in and out of bushes surrounding open areas. The intention is to drive smaller prey hiding within bushes into the waiting jaws of other pack members waiting in the open area. A frequent manoeuvre involves cutting corners while chasing prey. A single dhole chasing a prey animal is aided by others who run at the animal from other angles, reducing the distance between the lead dhole and the prey. This behaviour is often mistaken to be more than one dhole running relays. Sometimes, on being confronted with a dhole in front of it, the prey animal turns back into the rest of the pack. Such chases, though gruesome to watch, are exciting and ripe with scientific information (see *Figure 2*).

R SUKUMAR

***Figure 2** A dhole defending its kill from vultures. A total of 5 dholes killed this chital stag in the Kanha National Park, Madhya Pradesh.*

An Endangered Species

It is disheartening that a scientifically valuable species such as the dhole faces a severe threat to its survival. As mentioned earlier, the hunting strategy requires a very specific distribution of prey which in turn requires a unique habitat. One can envisage that such a delicate system is constantly under threat due to human

population pressures on valuable forest land. Cattle grazing, firewood extraction and increased real estate development are just some of the threats facing dholes today. The African hunting dog (*Lycaonpictus*) was an animal classified as vermin just sixty years ago. Today the species is highly endangered and has disappeared from much of its former range in Africa. Will the remarkable dhole follow in its footsteps? Very likely, unless immediate action is taken.

Suggested Reading

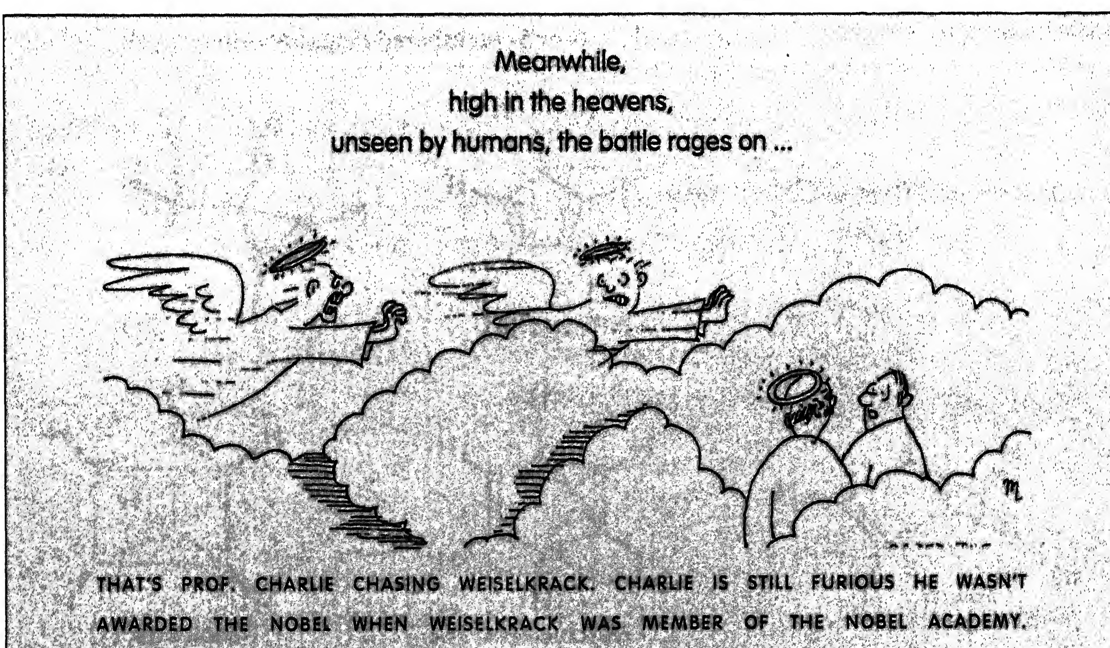
A J T Johnsingh. Ecology and Behaviour of the Dhole (Cuon alpinus), *J. Zool. (Lond.)* 198: 443-463. 1982.

M W Fox. The Whistling Hunters: Field Studies of the Asiatic Wild Dog (Cuon alpinus). State University of New York Press, New York. 1984.

R C Morris. The Indian Wild Dog (Cuon dukhanensis) *J. Bombay. Nat. Hist. Soc.* 30(1): 218-219. 1931.

A Venkataraman, R Arumugam and R Sukumar. Foraging Ecology of Dhole (Cuon alpinus)in Mudumalai Sanctuary, South India. *J. Zool. (Lond.)* in press. 1995.

Address for correspondence
Arun Venkataraman
Asian Elephant
Conservation Centre,
Centre for Ecological
Sciences, Indian Institute
of Science,
Bangalore 560 012, India.



MOHAN DEVADAS

Molecule of the Month

Isomers of Benzene – Still Pursuing Dreams

J Chandrasekhar

J Chandrasekhar is at the Department of Organic Chemistry of the Indian Institute of Science, Bangalore.

Three new monocyclic C_6H_6 isomers which are highly strained have been made in recent years.

Michael Faraday opened up a new chapter in chemistry when he isolated benzene from the distillate of coal tar. The deceptively simple molecule with the formula C_6H_6 has triggered many experiments and theoretical proposals. The correct ring structure, shown in 1 (see *Figure 1*), was assigned by Kekulé after his celebrated dream of a snake attempting to swallow its tail. Some chemistry historians are debunking this bit about the dream. But it may be too late; fact or fable, it is now part of chemistry folklore.

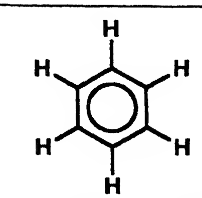
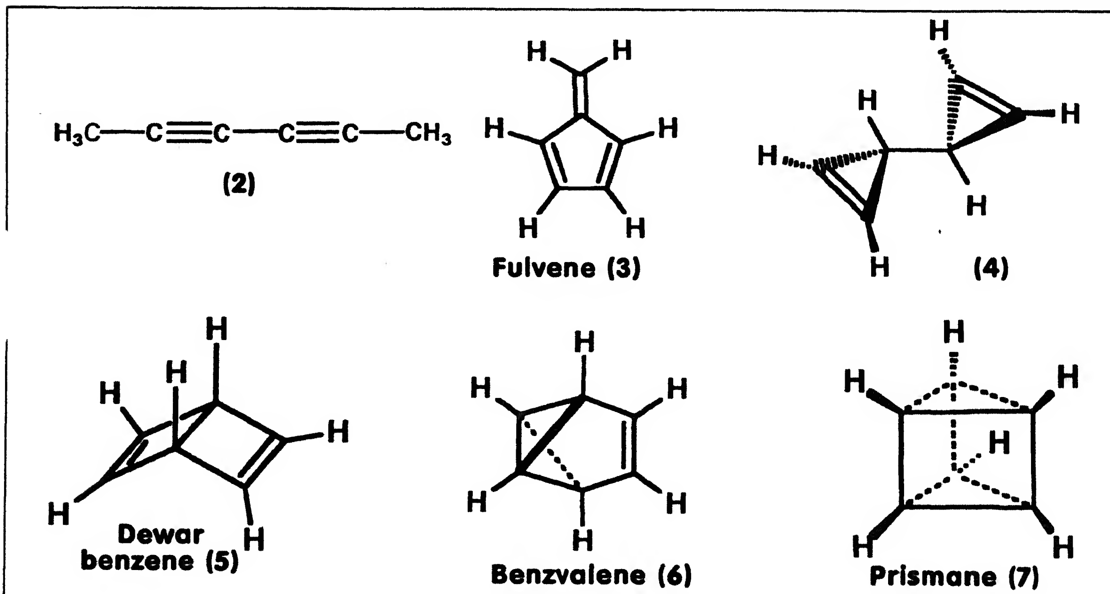

(1)

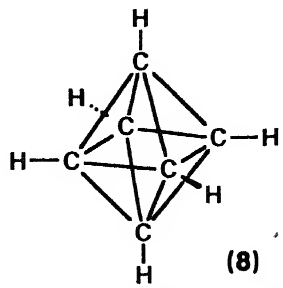
Figure 1 Kekulé structure of benzene shown with delocalised π electrons.

How many isomers are possible for C_6H_6, using the known rules about hydrocarbons? Many acyclic structures, such as dimethylbutadiene (2), readily come to mind. A large number of substituted 3-, 4- or 5- membered rings are also possible. Fulvene

Figure 2 Some experimentally known C_6H_6 isomers.



(3) is a famous example. Two 3-membered rings can also be connected to form C_6H_6, as in isomer **4**. Among bicyclic structures, Dewar benzene (5) is well known. (Can you think of others?) It was first proposed as a bonding model for benzene. Later, an independent isomeric structure, with a non-planar geometry was made. A more complex ring fusion is involved in benzvalene (6). This strained molecule has also been successfully synthesized. More rings can be added until we reach the highly symmetrical structure, 7, appropriately called prismane. This isomer was obtained as one of the products by photolysing Dewar benzene. Octahedrane (8) would have been a beautiful structure, but the valency of carbon does not permit this form.



(8)

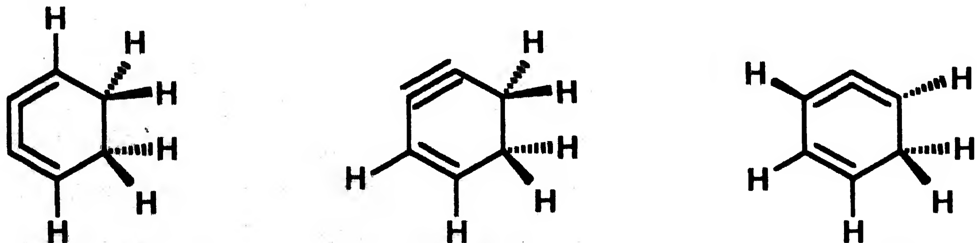
Figure 3 An impossible structure for C_6H_6

After all the isomeric structures are written down, the final count turns out to be 217! Only a small fraction of these have been made so far.

Consider only those isomers which have a 6-membered ring. Enamoured as we are by the symmetry and aromaticity of benzene, many of us would not even dream of an alternative to **1**. But, believe it or not, a *chemist* named William Shakespeare has proven the existence of two such isomers.

What are these 'Shakespeare benzenes'? The correct chemical names are 1,2,3-cyclohexatriene (**9**) and cyclohexen-3-yne (**10**). The former has three double bonds in a row (a butatriene unit), while the latter has a triple bond and a double bond. The central

Figure 4 New monocyclic isobenzenes.



(9) (10) (11)

Shakespeare benzenes **Christl benzenes**

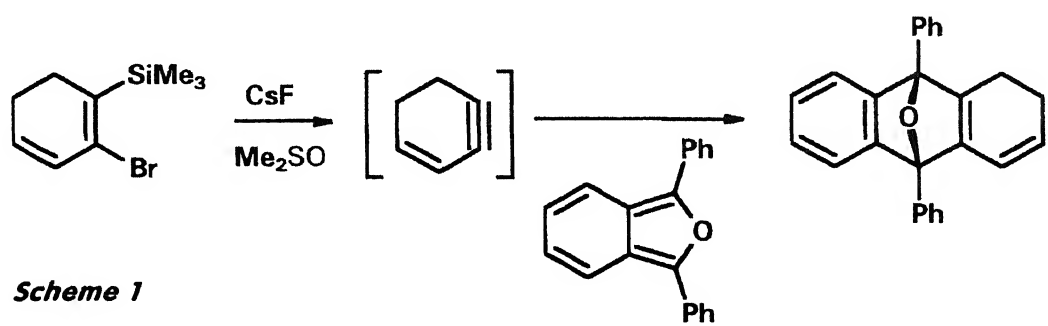
atoms of the butatriene unit and the atoms forming the triple bond prefer linear geometry ('sp' hybridisation). This is impossible in a 6-membered ring. Hence, both molecules are highly strained, besides lacking aromatic stabilisation.

The isomers **9** and **10** were made using standard methods for making butatrienes and enynes, respectively, from appropriate 6-membered ring precursors. In view of their high strain, the isobenzenes could not be isolated and characterised. However, the formation of these species was proven by trapping them as cycloadducts with a reactive furan (see *Schemes 1, 2*).

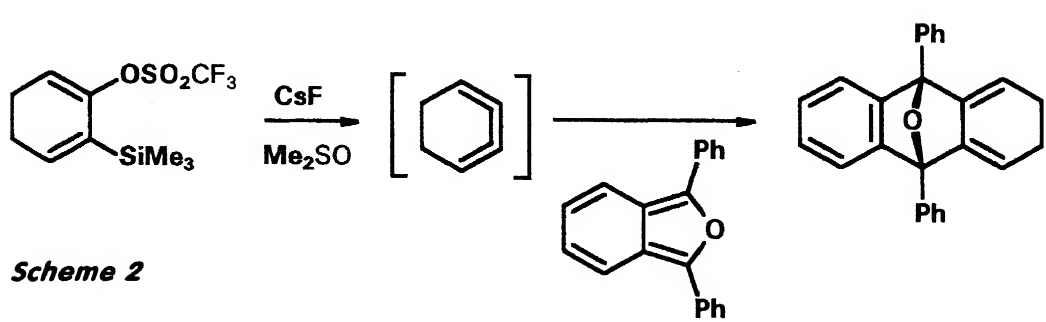
***Scheme 1** Experimental route to the preparation and trapping of cyclohexeneyne.*

***Scheme 2** Experimental route to the preparation and trapping of 1,2,3-cyclohexatriene.*

Spurred by this success, another isobenzene was created by a German chemist Christl. This new structure, 1,2,4-cyclohexatriene (11), has an allene unit and a double bond constrained in a 6-membered ring. Allenes do not like to be planar. Part of the strain

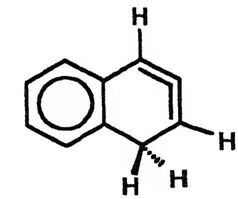


Scheme 1



Scheme 2

can be relieved by the hydrogen atoms bending out-of-plane. However, the molecule is expected to have considerable diradical character. The formation of 11, following successive elimination reactions from a suitable precursor, could be confirmed only by means of a chemical trapping experiment (see *Scheme 3*).



(12)

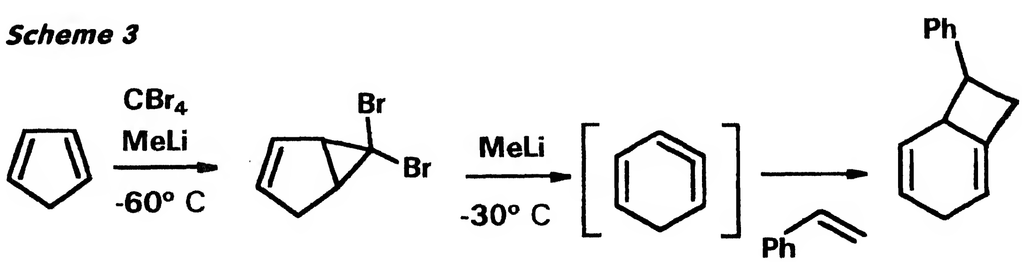
***Figure 5** Christl napthalene.*

We may expect more such work, especially aimed at the more strained forms, to complete the tally of benzene isomers. But surely the search has to end at 217? More likely, it won't. Benzene is only the first member of the aromatic series of compounds. There is the question of similar isomers for naphthalene, anthracene, etc. Christl has already considered and prepared his isomeric version of naphthalene (12). Further, if we are prepared to introduce enormous strain in the molecule, we should also consider the possibility of high energy isomers in which the valency restrictions are partially removed. As pointed out by another William Shakespeare:

"There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy".

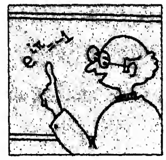
***Scheme 3** Reaction sequence used to prove the existence of 1,2,4-cyclohexatriene.*

Scheme 3



Did you know? ... When lead is bombarded by neutrons for a long time, it rearranges itself internally and becomes so elastic that a bell made of it might chime as resonantly as bells cast from the best bronze.

Address for correspondence
J Chandrasekhar
Department of
Organic Chemistry,
Indian Institute of Science,
Bangalore 560 012, India.



In this section of Resonance, *we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.*

? Diatomic molecules of the type A-B are polarised such that the more electronegative atom has a negative charge. However carbon monoxide (CO) has a small dipole moment with the negative end at carbon? What could be the reason?

? We are familiar with σ and π bonds in molecules. Can there be a δ (delta) bond? Is there any well characterised example of a compund containing a δ bond? (Hint: This may be treated as a question in inorganic chemistry.)

? In a laser beam, many photons occur with the same direction, frequency and polarisation. Is this an example of Bose-Einstein condensation (BEC)?

? A collection of non-interacting Bose particles exhibit BEC at low temperatures. How is this possible in the absence of interparticle forces? One usually assumes that an ideal gas does not condense.

On Bunsen Burners, Bacteria and The Bible.

From Milind Watve of M E Society, Abasaheb Garware College, Karve Road, Pune 411 004, India.

One of the key concepts of microbiological and biotechnological work is aseptic handling. One may be handling plant or animal tissue cultures, microbial cultures, injectable drugs or the like; it is essential to keep them away from contaminating micro-organisms. Micro-organisms are present in the air, on solid surfaces, on the skin of the worker and they are thrown out along with coughing, sneezing or even breathing by the worker. This makes things tricky. One can sterilize bottles, test tubes and media. How are we to sterilize the air in the working room, or ourselves for that matter? Nonetheless, there are ways of working which reduce the probability of contamination to an acceptable low level. These are called aseptic techniques. Industrial, analytical or research units usually have a device called laminar flow system in which sheets of sterile air are passed over the working area. Laminar flow systems are somewhat expensive; all undergraduate teaching laboratories cannot afford them.

What do the undergraduate laboratories then do? The students are told to take a pair of bunsen burners and keep them burning at a distance of roughly six inches from each other. One is supposed to work within this six inch zone which is comfortably sufficient after some practice.

Some fifteen years ago my teacher had told me: "Look, when you light the burners, the air expands and moves away. So if you open the mouth of a test tube in this area, contaminants from the outside air are unlikely to enter the test tube. You can thus get your work done aseptically".

Three years ago I was explaining this concept to a batch of first year B.Sc students in exactly the same way I had heard it from my teacher some fifteen years ago. "Look, when you light the burners, the air expands and moves away. So if you open the mouth of a test tube in this area, contaminants from the outside air are unlikely to enter the test tube. You can get your work done aseptically".

Batch after batch of students, have accepted these arguments. But that day one particularly adamant boy did not oblige. We argued

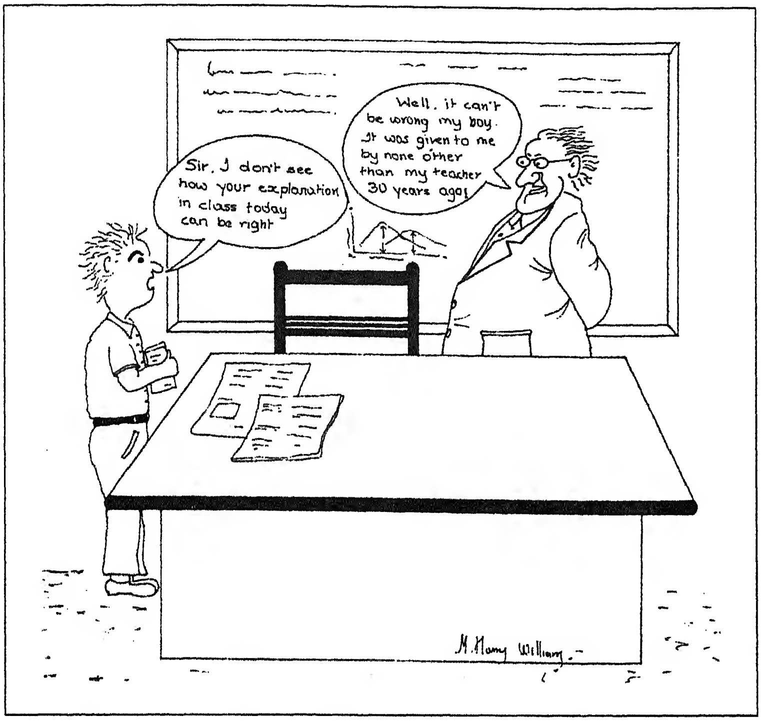
To confirm the aseptic technique which my teacher taught me, my students and I decided to look at the distribution of bacteria themselves in and around the burners.

about the air currents but did not reach a consensus. So we decided to experiment. An easy way, I thought, would be to generate visible aerosols so as to have a visual idea about them. We burnt some paper and took the small charred pieces that drift with the slightest air current. This worked to some extent, but no clear picture emerged. Then we decided to look at the distribution of bacteria themselves in and around the burners. A very simple technique is to expose gels of nutrient media for a defined time in specific locations. If bacteria floating in air come in contact with the gel, they get stuck and start growing because of the nutrients provided. If incubated overnight, they form visible colonies which can be counted. This does not ensure a count of the total number of organisms in a unit volume of air, but gives a relative account of the aerial load of micro-organisms. We did the experiment by exposing nutrient agar plates at various distances and heights from the flames of the bunsen burners and incubated them. The next day I intended to demonstrate that the plates exposed within the six inch aseptic zone carried a few or no bacteria, and as the distance from the burners increased, the number of colonies on the plates increased.

To my surprise it didn't work! The plates exposed within the aseptic zone had nearly the same number of colonies as those exposed a couple of feet away. Why was this so? Something must be seriously wrong. It made me think harder of all possible ways in which the experiment could have gone wrong. I carefully redesigned the experiment. The time of exposure was more rigidly standardised. Randomization was introduced to get rid of possible biases such as distance from wash basin, distance from the experimenter and so on. With the help of fifteen students, we exposed thirty pairs of plates within and outside the aseptic zone, this time with the hope of getting a 'correct' result.

We were expecting to demonstrate that within the six inch aseptic zone there would be few or no bacteria. To our great surprise, this didn't happen.

We took the counts the next day. To my disappointment the counts hardly differed. I tried all possible statistical jugglery that I knew, to try and show at least marginal statistical significance, so that I could somehow push the argument and save my face. But



M HARRY WILLIAM

We redesigned the experiment more carefully, introduced randomization to eliminate biases, but the bacterial count within and outside the aseptic zone hardly differed!

all parametric and non-parametric methods failed to show a significant difference.

Then I suddenly felt "why should I try to save my face?" So far I had accepted an argument because my teachers said so. It is not necessarily correct. Now that the experimental findings went against what I was taught, should I believe my teachers or should I have more faith in my experimental results? Certainly, I should trust my own findings, in the true spirit of science. It took a little time for me to become determined enough to declare in the class that the lesson that we had learnt from our teachers was certainly wrong.

On the basis of our experimental findings, I had to conclude that the lesson which my teachers taught me was certainly wrong.

I then decided to carry out a deeper investigation into the origin of this concept. I discovered that no textbook clearly advises us to work within the space of two burners. There is no authentic report that quantitatively studies the microbial load of the so-called aseptic zone. Most of all, the aseptic zone concept seems to be

We teach science as if we were teaching the Bible, the Bhagavad Gita or the Koran. Every word in those texts is sacred and unchallenged.

restricted to only a few universities, where it is propagated by vertical transmission. I say so because my teachers said so, who in turn took it from their teachers, the origin being uncertain. I talked to a large number of microbiology teachers and their reactions were surprising. The most common reaction was "May be, if you say, it could be so." ("but", reading between the lines, "we will continue teaching the same.") Another common reaction was, "working between the burners may be ineffective, but what can we do if we can't afford laminar flow systems?". (This is like trying to light an electric bulb with a match box and saying: what else can we do if there is no power?). One teacher said, "Oh, as it is, we have to teach a lot of rubbish. What difference does it make?" I wish at least one teacher had repeated the experiment and checked it himself. Out of all the students who participated in the experiment, only a handful really believed in their own experimental results and were ready to defend it. Others took a very diplomatic stand — they declared that if their examiner believed in an aseptic zone, it was real. If he didn't, it wasn't.

Our college students are so well-trained to believe that the teacher's word is final that before they peep into the microscope, they know what they are supposed to observe and they observe and draw it — even if a mischievous teacher like me puts a blank slide!

There are many generalizable lessons arising out of this story. It reflects our style of science teaching in general. We teach science as if we were teaching the Bible, the Bhagavad Gita or the Koran. Every word in those texts is sacred and unchallenged. If you happen to observe something which contradicts what you are supposed to teach, then your observation must be wrong. The textbooks and the teachers are the supreme authorities. So whatever the textbook says is correct and whatever the teacher says is final. So well-trained are our students in this tradition that before they peep into the microscope, they know what they are supposed to observe and they observe and draw it, even if a mischievous teacher like me puts a blank slide under the lens. As a student goes to the higher classes, his natural instincts are killed and he becomes a blind follower.

One might have a different experience in high school. With just a little encouragement, the students explore things on their own, observe more honestly and interpret more independently. Let me

relate, for comparison, a school experience. There is an experiment in textbooks about measuring the percentage of oxygen in air. What the textbook prescribes is this: take a bowl with a little water, light a candle at the centre and then place an inverted glass over it. Soon the flame gets extinguished and water will rise in the glass to occupy about 20% of its volume. This proves that oxygen occupies 20% of the volume of air. I remember the experiment as well as the figure in my textbook, decades back. Nothing has changed. As a student, I had accepted it blindly. We used to have our experiments only in books. The concept of doing an experiment was simply non-existent. As a teacher, I started doubting the experiment. What about the carbon dioxide produced? What about the temperature changes associated with burning and extinguishing the candle? Won't the air expand and contract?

With just a little encouragement, the students explore things on their own, observe more honestly and interpret more independently.

One batch of students actually did the experiment. It works, in the sense that some amount of water rises. What I was astonished by was a variation of the experiment. One boy decided to burn two candles instead of one. To everyone's surprise, water was seen rising to a higher level. What followed was the most logical conclusion from the students, "When one burns two candles, there is more oxygen in the air!".

I leave it to the readers to do the experiment and reach their own conclusion.

Did you know? ... One can measure deformations that are less than an atomic diameter — provided they are oscillatory and thus can easily be transformed into electric signals. The human ear can also "measure" similarly small deformations of the eardrum. (from *Quantum*, September-October 1995).

Did you know? ... It is possible to combine opposite mechanical properties in "composites" — compound materials that include a light pliable base and a fibre filling made of a very strong material. (from *Quantum*, September-October 1995).

Think It Over

This section of* Resonance *is meant to raise thought-provoking, interesting, or just plain brain-teasing questions every month, and discuss answers a few months later. Readers are welcome to send in suggestions for such questions, solutions to questions already posed, comments on the solutions discussed in the journal, etc. to* Resonance, *Indian Academy of Sciences, Bangalore 560 080, with "Think It Over" written on the cover or card to help us sort the correspondence. Due to limitations of space, it may not be possible to use all the material received. However, the coordinators of this section (currently A Sitaram and R Nityananda) will try and select items which best illustrate various ideas and concepts, for inclusion in this section.

From J Chandrasekhar

1 The Richness of Chemistry

One simple way to appreciate the richness of chemistry is to go through the following exercise: Think of any two elements in the Periodic Table. Try to work out the number of possible binary compounds that can be made from them. Then, check how many have indeed been made experimentally. Invariably, you will come to the conclusion that a large chunk of chemistry remains unexplored.

Think of any two elements in the Periodic Table. Try to work out the number of possible binary compounds that can be made from them. Then, check how many have indeed been made experimentally. Invariably, you will come to the conclusion that a large chunk of chemistry remains unexplored.

Let us try this procedure for carbon and oxygen. How many oxides of carbon are known? Carbon monoxide (CO) and carbon dioxide (CO_2) would immediately spring to mind. The former is a colourless, odourless poisonous gas emitted all around us by the incomplete combustion of carbon compounds. It is also the key ingredient of the industrially important 'water gas'. Carbon dioxide, present in larger amounts in the atmosphere, is useful as dry ice and provides the fizz in soft drinks. It is also the prime suspect in the global warming process caused by the greenhouse effect.

Are there any other oxides? Text books usually list carbon suboxide, C_3O_2. More advanced inorganic books mention a few more.

However, one can easily write the formulae of several possible oxides. One can generalise and have a series of oxides of the formula C_nO and another of the type OC_nO. The first few members in both the series have been made in the laboratory. Their structures have been determined by microwave (or rotational) spectroscopy. Some have been detected first in inter-stellar clouds, by their characteristic spectral features, and confirmed later by laboratory experiments.

Carbon dioxide, present in larger amounts in the atmosphere, is useful as dry ice and provides the fizz in soft drinks. It is also the prime suspect in the global warming process caused by the greenhouse effect.

Based on the nature of hybridisation of the atoms involved, the two series of compounds are expected to be linear. But there is another interesting pattern in their electronic structures. In the series of linear molecules with the general formula C_nO, the ground electronic state is a singlet if n is odd and a triplet if n is even. There is a qualitative explanation based on molecular orbital theory for the trend (although the space in the margin is not enough to write it down). Can the rule be extended to the OC_nO series of molecules too?

Finally, one must mention the oxides of fullerenes. Just as C_{60} and C_{70} are unique molecular allotropes of carbon, their oxides are entities in themselves. Both $C_{60}O$ and $C_{70}O$ have been made, retaining the spheroidal shapes of the fullerenes. How many reasonable isomeric structures are possible in each case?

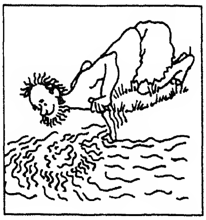
2 Prisoner's Dilemma

Three prisoners, *A*, *B* and *C* are each held in solitary confinement. *A* knows that two of them will be hanged, but one will go free. However, he does not know who will go free. He thus reasons that there is a 1/3 chance of his survival. Anxious to know his fate, he asks his guard. But the guard will not tell *A* his fate. *A* thinks and puts the following proposal to the guard: "If two of us must die, then I know that either *B* or *C* must die and possibly both. If you tell me the name of just one of them who is certain to die, then I learn nothing about my fate; and since we are kept apart, I cannot inform them of theirs. So tell me which one of *B* or *C* is to die?" The guard accepts the logic and tells *A* that *C* is to die. *A* now reasons that either he or *B* will live. Thus *A* now has a 1/2 chance of survival. Is *A*'s reasoning correct?

Will the knowledge of probability theory resolve the prisoner's dilemma?

The Crisis of Science

Satyendra Nath Bose



***Reflections* carries material on the history and future of science, its methodology and philosophy, and its connections with other human activities. It is intended to provide a broad view, complementing the more specific discussions of individual topics in the rest of the journal.**

A new age in physics has dawned from the beginning of the 20th century. Let us make a few general comments on the historical development of physics before we proceed to analyze the characteristics of this new age.

It is perhaps not an exaggeration to state that modern science began with Newton. Before the time of Newton, many isolated facts were known about the physical world in a disconnected fashion. From time immemorial, man has been collecting such knowledge which might be of practical use in his daily life or which might lead to greater efficiency and productivity in the crafts and the trades. But the only example of a pure science in the ancient world was mathematics. Especially geometry was a subject which commanded the attention of scientific thinkers. The ancient Greeks and their followers developed certain approaches and methods for the study of geometry. Later scientists attempted to apply these same approaches and methods to study material objects. That is why Euclid is revered as the father of all exact sciences. It was Newton who first showed that motions of material bodies can be studied by the mathematical methods previously applied only to geometry. The central problem of dynamics is to find out how the future configurations and motions of material bodies can be predicted from a knowledge of their present configurations and motions.

Newton found the solution to this problem of dynamics. His successors demonstrated that his laws hold sway from the stars in the sky to terrestrial objects of different sizes around us. The results and predictions based on these laws gave remarkable agreement with what was directly observed. It

Translator's Note

This is an essay which appeared in the Bengali magazine *Parichay* in the issue of August-September 1931. S N Bose, the creator of quantum statistics, always had the conviction that we ought to present science to the common man in his own language. In later life, he nurtured a Bengali magazine for popular science. His interest in presenting science in Bengali, however, began quite early in life. The present essay is his first published writing in Bengali at a time when quantum mechanics was in its infancy. In brilliant and lucid Bengali prose, he provides a masterly account of the developments of physics which led to the quantum crisis. This is truly an extraordinary piece of popular science writing in every sense. Perhaps it will be difficult to find a comparable essay in any Indian language where a master of such stature describes to laymen a recent revolution in his field of research. Bose's colleague, M N Saha, did a considerable amount of non-technical writing in English, which appeared in the magazine *Science and Culture*. Since Bose's non-technical writings are all in Bengali, his talents as a popularizer of science are not generally known outside his native Bengal. This translation may give some idea of his style and presentation.

It may be noted that this essay was written before the discovery of the neutron. Bose therefore considers electrons and protons to be the only constituents of matter. I should also mention that I have followed Bose in referring to electromagnetic waves as waves in the ether. As one of the first translators of Einstein's papers on relativity into English, Bose must have been aware that the concept of ether was no longer so useful. Perhaps he felt that a lay person would grasp the concept of waves in ether more easily than the concept of electromagnetic waves. One may also note that Bose, in his characteristic modest way, never even mentions his own famous work of 1924 which could have quite naturally found a place in this essay.

Arnab Rai Choudhuri

became possible to predict at which point in the sky a planet would appear two years from now by doing calculations today. One could also predict the trajectory that a cannon ball would follow and find out exactly where it would land behind the enemy lines. Encouraged by these successes, the scientists began investigating other aspects of the material world. Heat, light and electricity became the phenomena to be studied next. Following the footsteps of Newton, later scientists tried to carry on similar mathematical investigations of these phenomena and achieved a fair degree of success.

Scientists from the earliest times have bothered about the

"It is perhaps not an exaggeration to state that modern science began with Newton. "

"Scientists from the earliest times have bothered about the ultimate constituents of matter. Human mind has pondered over the question whether there is some kind of fundamental building block out of which the whole physical world with all its apparent diversity is made up."

ultimate constituents of matter. The human mind has pondered over the question whether there is some kind of fundamental building block out of which the whole physical world with all its apparent diversity is made up. A long tradition of research has finally culminated in the modern view of chemistry that everything around us has resulted from different combinations of only 92 elements. These elements are the constituents of all material objects starting from wood and stones to the bodies of animals. To demonstrate the correctness of this assertion, chemists are able to synthesize more and more substances artificially in their laboratories.

At one time it was a complete mystery to scientists how complex substances are produced by natural transmutation processes - sometimes deep down under the Earth's surface, sometimes within the living bodies of animals. Modern chemical analysis has shown that all these substances are made up from the same elements, and chemists have now succeeded in synthesizing many of them starting from the basic elements. A search for the laws governing these analyses and synthesis processes has given rise to a scientific atomic theory. The modern scientific view is that all solids, liquids and gases are made up of atoms. Whether a substance is found in the solid, liquid or gaseous state merely depends on the motions and mutual interactions of the atoms. To establish this point of view with certainty, scientists had to address the question whether the dynamics of the invisible atoms is governed by the same laws of mechanics which govern the dynamics of visible objects around us. Towards the end of the 19th century, Thomson, Rutherford and other scientists came to the conclusion that these 92 elements themselves must contain two types of subatomic particles. One of them is the positively charged particle proton, whereas the other is the negatively charged particle electron. It seems that all atoms are made up of just these two fundamental particles. Scientists have arrived at this conclusion by a kind of scientific analy-

sis, which in some ways reminds us of the analysis through which the chemists had earlier established the existence of 92 elements.

This view of the ultimate constitution of matter became firmly established by the turn of this century. The main task of physics today is to discover the laws which determine how these two types of charged particles make up the atoms of all the different elements. Experiments performed by Rutherford and others at the beginning of the century suggested that the structure of the atom resembles the structure of the solar system in which the planets revolve around the Sun obeying Newton's laws of motion. It appears that each atom has a nucleus within which positively charged particles outnumber negatively charged particles. Several negatively charged electrons revolve around this nucleus in different orbits. The net positive charge of the nucleus equals the total negative charge of the electrons in all the orbits. Consequently the whole atom appears as an uncharged entity in experiments which do not resolve the subatomic structure. Since all the fundamental particles possess the same quantity of charge, the 92 different elements essentially differ because of the different numbers of orbiting electrons within their atoms. The heaviest metal has 92 electrons moving round the nucleus. Rutherford and others have provided strong evidence in support of this model of the atomic structure. The properties of different elements can be explained from the different electronic structures of their atoms. It is becoming increasingly clear that many macroscopic properties of bulk matter are related to the electrical charges of the subatomic particles. But we still do not fully understand the laws of physics which govern the motions of electrons around the nucleus.

At this point, it is essential to examine some concepts which physicists had developed from their studies of heat and light. Since a solid is perceived by the physicist as a collection of

Satyendra Nath Bose
1894-1974

"Experiments performed by Rutherford and others at the beginning of the century suggested that the structure of the atom resembles the structure of the solar system in which the planets revolve around the sun obeying Newton's laws of motion."

"Heat is nothing but the macroscopic manifestation of the motions of molecules... a substance appears hotter when the molecules inside are more energetic."

many vibrating molecules, it is natural to conclude that heat is nothing but the macroscopic manifestation of the motions of molecules. When we keep one end of a metal rod in a furnace, the other end also gradually gets heated. The explanation for this is that the energetic molecules of the furnace collide with the less energetic molecules of the initially cooler rod and transfer some energy to them. The interactions amongst the molecules of the rod then transmit this energy to the end of the rod away from the furnace. A substance appears hotter when the molecules inside are more energetic. Scientists are trying to explain different thermal properties of matter on the basis of this idea. This has naturally led to the discussion whether Newtonian mechanics is applicable to the motions of molecules. Calculations based on Newtonian mechanics have given some promising results. Here, however, one has to keep in mind that it is not possible to carry out detailed calculations of the motions of all molecules the way it was done for the planets. We have seen that one can predict the future motions of planets from a knowledge of their positions and velocities at some instant of time. It is impossible to have such detailed knowledge for all the molecules within a material body. We are able to say something definite in spite of this limitation only because we are dealing with a very large number of molecules. In order to understand bulk properties of matter, it is not essential to have exact knowledge about each and every molecule. If we merely know the laws which in general govern the motions of the molecules, then that is often sufficient to explain many of the thermal properties. We can give the example of a country in which millions of people live. Even though we may not have detailed information about the occupations of all the people, we can still study the general economic prospects of the country and its statistics of births and deaths. Often this limited knowledge suffices to draw many important inferences. In exactly the same way, we can study the motions of molecules within some bulk material from a statistical point of view.

Physicists have the faith that the laws of Newtonian mechanics have the same kind of definiteness as the axioms of geometry and other branches of mathematics. When calculations based on these laws gave fantastic agreement with experiments, scientists expected that any ideal scientific theory should have a similar kind of definiteness. Our discussion in the previous paragraph should make it clear that such definiteness is not expected in the theory of heat. Today when the physicists are viewing the whole material world as collections of electrons and protons, and are trying to explain all phenomena from the electrical interactions of these fundamental particles, it is not clear that the laws they are arriving at should have the same definiteness as the axioms of geometry. Some of the current ideas of physics should be taken more as working hypotheses which yield results in agreement with experiments. On some future occasion, I wish to elaborate upon the differences between the axioms in a subject like geometry and some of the current laws of physics which are more of the nature of provisional working hypotheses.

Space provides the stage on which electrons and protons act as the *dramatis personae*. There was a time when physicists used to think of electrons and protons as ordinary material spheres in every respect apart from the very small size. Since the sizes of these subatomic particles appeared much smaller than the atom, it seemed natural to conclude that an atom has mostly empty space inside. Physicists started thinking about the nature of the empty space when it was realized that most properties of light can be understood adequately by assuming light to be some kind of wave motion in space. From the beginning of the 19th century, a hypothesis started gaining ground that the whole universe is filled with some continuous substance called *ether*. The atoms or subatomic particles are then floating in this ocean of ether. Light is nothing but the waves in this ocean. There can be waves of different wavelengths in this ocean, which all propagate with the same speed

"Physicists have the faith that the laws of Newtonian mechanics have the same kind of definiteness as the axioms of geometry and other branches of mathematics."

"The main conclusion of modern physics is that all the phenomena occurring in the natural world can ultimately be understood in terms of the interactions amongst the fundamental particles inside the atom and their interactions with the waves in the ether."

in vacuum. The different colours of light are caused by the differences in the frequencies of these waves. Today scientists know of ether waves which are both much larger and much smaller than the waves which produce the sensation of light in our eyes. Today man has learnt some techniques by which waves of certain types can be started in ether. The radio waves, which carry information over thousands of miles, are examples of such man-made waves in the ether. These waves are much larger than the ordinary waves of light. On the other hand, the X-rays, which are now being widely used in medicine, are also waves in the ether which are much smaller in size.

Although the Moon, the Sun, the planets and the stars are very far from the Earth, they are all linked by being immersed in the same ether. We receive the light from the stars and the nebulae through the waves in the ether. The ether transmits the heat and the light from the Sun to us as well, making the Earth vibrate with life, enabling man both to harness the energy and to misuse it for different purposes. Much of the energy coming from the Sun has been transformed and stored in diverse forms on the surface of the Earth. The main conclusion of modern physics is that all the phenomena occurring in the natural world can ultimately be understood in terms of the interactions amongst the fundamental particles inside the atom and their interactions with the waves in the ether. The primary goal of 20th century physics is to discover all the laws governing such interactions.

This brief outline of how physics developed from the time of Newton to the 20th century provides an exmaple of the unending strivings of the human mind. By the 18th century, the mathematical scientists who followed Newton managed to solve most of the problems of planetary astronomy by applying the laws of mechanics. Newtonian mechanics already came to be regarded as the supreme example of an ideal

physical theory. It was thought as inconceivable that there could be limitations to Newtonian mechanics. The scientists of that period thought that the one or two still unresolved problems of planetary astronomy merely reflected their inability to apply the principles of mechanics properly. Well into the 19th century, physicists kept nurturing the view that any physical theory should be based on a few fundamental principles having the same kind of definiteness as the axioms of geometry or Newton's theory of gravitation. With the development of the atomic theory of heat, physicists started recognizing the importance of statistical theories which were somewhat different in nature from the previous theories. At the end of the 19th century, it became necessary to think anew what the nature of a physical theory ought to be. Finally the study of light precipitated the ultimate crisis. Let me mention only this: when the well-known laws of dynamics were applied to study the interactions of light with atoms, the results were in complete disagreement with experiments. This led Planck to propose the quantum theory in 1900. The central idea of this theory is the following. Although most of the previous results of optics were consistent with the wave theory of light, Planck showed that we have to adopt a different point of view when we consider the emission or absorption of light by atoms. Although the propagation of light can be understood best from the wave theory, it is necessary to regard light as a stream of particles when we study the interaction of light with atoms.

Just the way chemists were earlier led to the atomic theory of matter while studying the reactions amongst different chemical substances, the study of reactions between light and matter led to the particle theory of light. According to quantum theory, light beams of different colours have different types of quanta. The energy carried by a quantum depends on the frequency of light, and typically one quantum is removed from the beam of light when an atom absorbs energy from the

"Well into the 19th century, physicists kept nurturing the view that any physical theory should be based on a few fundamental principles having the same kind of definiteness as the axioms of geometry or Newton's theory of gravitation."

Satyendra Nath Bose
1894-1974

"Although we were so far regarding electrons as very small particles, the experiments by a few scientists like Davisson and Germer showed that sometimes a beam of electrons can act like a wave. Just as light can be diffracted to give rise to fringes, a beam of electrons can produce similar patterns on hitting an obstacle."

beam. On the other hand, when the atom gives out energy, a quantum is produced. These ideas are completely contrary to what we expect in Newtonian physics. Niels Bohr and other physicists are trying in the last few years to develop a framework within which the quantum theory can be reconciled with the older ideas of physics.

Let me again summarize the nature of the crisis in optics. The questions arising from the study of propagation of light can be answered only by the wave theory, the particle theory being unable to handle these questions. On the other hand, questions pertaining to the creation or destruction of light can be answered adequately only by the particle theory. The wave theory fails completely in these situations. This crisis in physics has deepened further in the last four or five years as a result of some startling new discoveries pertaining to the nature of electrons. Although we were so far regarding electrons as very small particles, the experiments by a few scientists like Davisson and Germer showed that sometimes a beam of electrons can act like a wave. Just as light can be diffracted to give rise to fringes, a beam of electrons can produce similar patterns on hitting an obstacle.

All these developments have caused a revolution in physics in recent years. Neither material particles nor light can be treated according to our previous notions. Although we were accustomed to regarding electrons as tiny particles of charge, we are suddenly becoming aware that they can also behave like waves. On the other hand, light can no longer be considered simply as a wave, since it often behaves like a beam of particles.

A consequence of this revolution is that none of the laws of physics are now regarded as sacrosanct. We have got enough evidence that Newtonian mechanics does not hold in the world of atoms. So scientists are now busy examining the

foundations of all the theories of physics. Efforts are being made to ascertain which laws can still pass as scientific truth and which laws have to be rejected as being mere scientific constructions that served the earlier scientists. The concepts of space and time are also under scrutiny. All of physics is based on measurements connected with space, time and motion. One pertinent question is whether our theories can be based on some hidden quantities which are not measured. This is an age of critical self-questioning in physics. Physicists are now desperately trying to come to terms with many of the concepts, which were accepted without question in the 19th century when classical physics dazzled everyone with its brilliant and spectacular triumphs.

"This is an age of critical self-questioning in physics."

Bachelier got there first ... The first person to discover the connection between random walks and diffusion was Louis Bachelier, in a doctoral dissertation of 1900. The examiners, damning it with faint praise, gave it a *mention honorable* at a time when only a *mention très honorable* was considered worth having. Bachelier wasn't studying Brownian motion, however; he had his eye on something closer to the gambling origins of probability theory—the random fluctuations of the Paris stock-market. It's perhaps no surprise that a failed thesis on stocks and shares attracted little attention from theoretical physicists. In 1905 Albert Einstein laid what everyone thought were the foundations of the mathematical theory of Brownian motion; and Norbert Wiener developed these extensively. Only much later was it discovered that Bachelier had anticipated many of their main ideas!

Poisson's work ranged from calculus to criminal law ... Poisson paid considerable attention to the application of probability theory to criminal jurisprudence. He even wrote a treatise titled "A Study of Verdict Probability in Criminal and Civil Cases".

Nature's Solar Cell

Structure of the Light Harvesting Complex

Stephen Suresh and Gautham Nadig

The sun is the principal source of energy for all life on earth. Yet, only green plants and certain bacteria can directly use solar energy by converting the light energy into chemical energy. They do this by photosynthesis in specialised organelles called chloroplasts. The energy then trickles down to all the other organisms through the food chain. Ever since 1842, when Mayer discovered that plants convert solar energy to chemical free energy, scientists have been attempting to understand this fundamental process. Photosystem I, Photosystem II and the Cytochrome bf complex mediate the photosynthetic process. The molecular mechanism of photosynthesis is finally being unravelled by a combination of powerful techniques that include spectroscopy, molecular biology, X-ray crystallography and electron microscopy.

The key players in photosynthesis are two membrane-bound protein complexes in the chloroplasts, the 'light harvesting complex' (also called the antenna complex) and the 'reaction centre'. The light harvesting complex captures the light energy and transfers it to the reaction centre, which acts as a light-driven electron pump across the photosynthetic membrane.

The three-dimensional structure of the reaction centre from purple photosynthetic bacteria was determined by Harmut Michel and his colleagues at the Max Planck Institute in Germany. This was a landmark achievement in understanding photosynthesis and was recognized by the award of the Nobel prize for Chemistry in 1989. The recent determination of the structure of the plant light harvesting complex by Werner Kuhlbrant and his group at the European Molecular Biology Laboratories, and that of the bacterial light harvesting complex by N W Isaacs and his group at the University of Glasgow in 1995 marks yet another major step in the understanding of the molecular basis of photosynthesis. The structure of the light harvesting complex LHC II associated with photosystem II of green plants was solved by electron microscopy, while the corresponding complex LH2 from the purple

Photosystem I Assembly of about 13 polypeptide chains which catalyze the formation of NADPH, a strong reductant. It absorbs light of wavelength shorter than 700 nm.

Photosystem II Assembly of more than 10 polypeptide chains which catalyze the light driven transfer of electrons from water to plastoquinone. It can absorb light of wavelength shorter than 680 nm.

Cytochrome bf Complex A membrane bound protein complex that links Photosystem I and Photosystem II. It is responsible for the transport of electrons from Photosystem II to Photosystem I. Both Photosystems are composed of the light harvesting complex and a reaction centre.

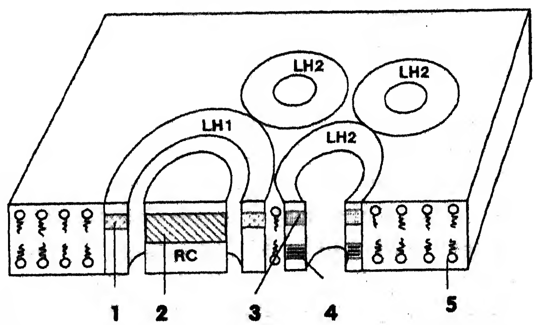
photosynthetic bacteria was elucidated by X-ray crystallography. With the knowledge of the three-dimensional structure, we are in a position to understand at the atomic level how photons are collected and funnelled to the reaction centre where photosynthesis takes place.

In bacteria, the photosynthetic machinery is embedded in small vesicles which are spherical structures made up of lipid bilayers. The light harvesting complexes with associated chlorophylls, carotenoid molecules and other chromophores and the all-important reaction centre are present in these vesicles. Most photosynthetic bacteria have two light harvesting complexes, LH1 and LH2. The omnipresent LH1 surrounds the reaction centre and has a number of LH2 complexes at its periphery. The number and the properties of the LH2 vary depending on the available light and growth conditions.

Structurally, the LH2 complex is ring shaped and is made up of 9 identical units, each consisting of 2 polypeptide chains named alpha and beta with 53 and 41 amino acid residues respectively. To each unit, 3 'bacteriochlorophyll a' (*Bchl a*) molecules and a carotenoid molecule are bound. It is interesting that, of these chromophores 2 of the 3 *Bchl a* molecules absorb light of a longer wavelength than the third, due to differences in their chemical environment. These 9 pairs of chlorophyll molecules that absorb at 850 nm (1 nanometer = 10^{-9} m) are arranged in a ring close to the periplasmic surface. Each molecule in the ring is in van der Waals contact with its neighbours on either side. The other 9 chlorophyll molecules that absorb at 773 nm form a ring in a plane 18Å directly below.

When a photon hits one of the chlorophyll molecules the absorbed energy spreads in about 200-300 femtoseconds (1 femtosecond = 10^{-15} seconds) to the other chlorophyll molecules in the ring through a mechanism called the exciton coupling. This mode of energy transfer is

***Figure 1** The membrane bound light harvesting complexes (LH1 and LH2) and the reaction centre (RC) in purple photosynthetic bacteria (Rhodopseudomonas acidophila). LH1 = light harvesting complex 1; LH2 = light harvesting complex 2; RC = reaction centre.*



1 Location of the chromophores in the LH1 complex
2 Location of the chromophores in the reaction centre
3 Location of the chlorophyll molecules that absorb at 850 nm in the LH2 complex
4 Location of the chlorophyll molecules that absorb at 773 nm in the LH2 complex
5 *Lipid molecule of the photosynthetic membrane.* Circular heads of the lipid molecule represent the polar part and the tail portions represent the hydrophobic part.

When a photon hits one of the chlorophyll molecules the absorbed energy spreads in about 200-300 femtoseconds to the other chlorophyll molecules in the ring through a mechanism called the exciton coupling.

made possible by the appropriate disposition and close arrangement of the chromophores within the ring. The energy is then transferred from one LH2 complex to another till it reaches the chromophores of an LH1 complex, which absorb at a longer wavelength. The LH1 complex then transfers the energy to the chromophores in its associated reaction centre (*Figure 1*). This extremely quick transfer of energy from LH2 to LH1 and to the reaction centre is facilitated by the positioning of the chromophores in each of the complexes at the same height. The photosynthetic process begins when the photon strikes a pair of chlorophyll molecules called the 'special pair' situated at the end of the reaction centre. An electron within the special pair absorbs energy from the photon and moves to a neighbouring molecule of pheophytin, a chlorophyll-like accessory pigment, leaving the special pair with an excess positive charge. This electron travels from one quinone molecule to a second quinone molecule on the periplasmic side of the membrane. The positive charge on the special pair of chlorophyll molecules is neutralised by an electron from a cytochrome C molecule permitting the special pair to absorb another photon and repeat the process over again. This results in the second quinone molecule having 2 extra units of negative charge. These quinone molecules now dissociate from the reaction centre to participate in the later stages of photosynthesis which take place at the outer surface of the membrane. Thus the reaction centre serves as a solar cell using light energy to bring about charge separation across the membrane. Nature's solar cell is highly efficient; it captures 98 -100 % of the incident photons. Half this energy is used in driving the electrons along the pathways of the photosynthetic pigments; while the other half gets stored as electrical potential energy across the membrane. Such depth of understanding of this fundamental process has been made possible only by the elucidation of the atomic structure.

Suggested Reading

Lubert Styrer. *Biochemistry*, W H Freeman and Company, San Francisco. 1988.

J Deisenhoter, W Michel. The Photosynthetic Reaction Centre from Purple Bacteria, Rhodopseudomonos viridis, *EMBO J.* 8:2149-2169. 1989.

W Kuhlbrant et al. Atomic Model of Plant Light Harvesting Complex by Electron Crystallography. *Nature* 367: 614-621. 1994.

Mc Dermott et al. Crystal Structure of an Integral Membrane Light Harvesting Complex from Photosynthetic Bacteria. *Nature* 374: 517-521. 1995.

Stephen Suresh and Gautham Nadig are with the Molecular Biophysics Unit, Indian Institute of Science, Bangalore 560 012. Stephen Suresh obtained his Ph.D degree from the Unit in 1995, while Gautham Nadig is working for his Ph.D degree at the Unit. Their interests are in the structures function relationships of macromolecules.

The Seven Component Coupling

A New World Record by Ivar Ugi and Co-workers

Uday Maitra

What is the maximum number of components which can be mixed together to form a product? Four, five, six... or more? The current world record is:seven!

In general, a chemical reaction proceeds only through unimolecular or bimolecular *elementary* steps. This is because the probability of three or more molecules coming together to interact at the same time is negligible. So, chemists generally use no more than two components in any given reaction step. (Of course, a catalyst may be added to accelerate the reaction). Complex molecules are made by sequencing many reaction steps, each involving a small number of components. After each step, the tedious and sometimes difficult task of isolating the product for further processing is carried out. The operation would be more efficient if at least some of the successive steps could be carried out without having to do the 'work-up'. One-pot synthesis is therefore quite popular with chemists (as with amateur cooks). It would be better if all the ingredients needed to make a molecule in a long sequence of reactions can be mixed at one go. But this involves the risk that some of the components may interact with each other or with one or more of the intermediates formed in the sequence in a manner which was not anticipated. This would lead to the formation of unwanted side products. Therefore, to be on the safe side, chemists avoid putting together too many components at any given time. This brings us to the following question: what is the maximum number of components which can be mixed together to form a product? Four, five, six... or more? The current world record is:seven!

A seven component coupling reaction was reported by Ivar Ugi and coworkers in *Angew.Chem.Int.Ed. Engl* (1993,*32*,563). The overall reaction stoichiometry is shown in *Figure 1*. Is it not incredible that you mix seven reactants in a vessel, and ultimately get a product in 43% yield (as a 2.5/1 mixture of diastereomers)? Such a multi-component reaction cannot obviously go through a single step for entropic reasons. A sketch of the reaction mechanism is given in *Figure 2*, which makes use of simple principles of organic chemical transformations. Using these steps, it is quite easy to see that the individual reaction steps are not unusual at all. It is only the clever combination of the reagents that has produced this remarkable seven-component reaction. Every component seems to wait for its turn to react with an intermediate product that is formed, without interfering with the logical sequence of Figure 2.

One-pot synthesis is quite popular with chemists (as with amateur cooks).

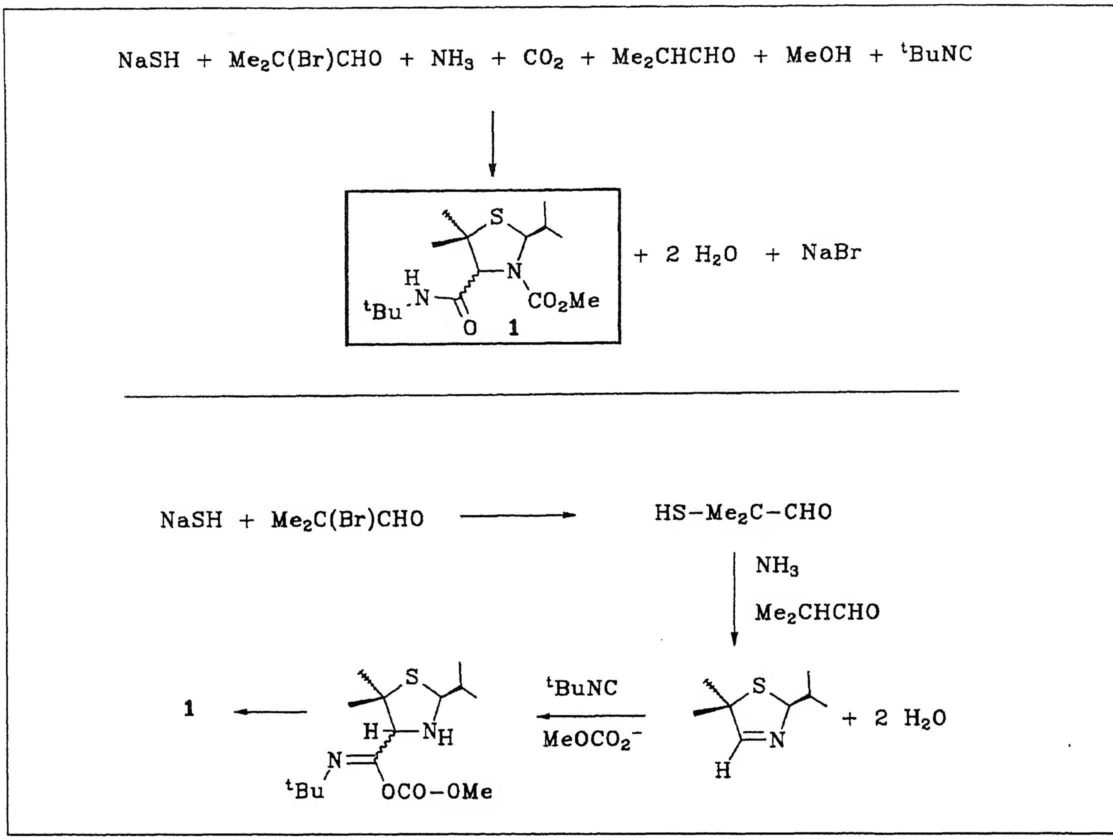


Figure 1, 2 Overall stoichiometry of Ugi's seven component coupling reaction (top). and a rational mechanism of Ugi's reaction (below).

The first step shown is a simple nucleophilic displacement reaction. The second step is formally a condensation reaction, in which a Schiffbase formed from isobutyraldehyde and ammonia undergoes coupling (in the protonated form) with the thiol-substituted aldehyde. The protonated form of this intermediate then undergoes a nucleophilic attack by *t*- butylisocyanide, and the resulting $-N{=}C^{+}-$ unit is trapped by $MeOCO_2^-$ anion. Finally, the CO_2Me group undergoes a 'transfer' from the oxygen to the nitrogen in the same molecule to produce 1.

Is it possible to have multicomponent coupling reactions with more than seven reagents? In principle yes, and perhaps some chemists are working towards this goal! We look forward to seeing an example which will break Ugi's record!

Uday Maitra is with the Department of Organic Chemistry, Indian Institute of Science, Bangalore 560 012, India.

Discoverers of the Neutrino and Tau Recognised

Particles that Acquired 'Nobelity'

K V L Sarma

The 1995 Nobel Prize in Physics is shared by the American physicists Frederick J Reines and Martin L Perl for their pioneering experimental contributions to 'lepton' physics. Leptons, such as the electron, do not feel the nuclear force but only the electromagnetic and the weak beta decay force. This year it is the turn of two of the six leptons of today's particle physics, the electron-neutrino ν_e and the τ lepton, tau, to acquire 'Nobelity'.

Frederick Reines (University of California, Irvine), now 77, with Clyde L Cowan Jr. (who died in 1974) reported the first direct evidence of the existence of the 'neutrino' in 1956. The neutrino is a tiny neutral particle hypothesized by Wolfgang Pauli Jr. in 1930. Twenty five years later and with the invention of the nuclear reactor it was possible to verify its existence.

This year's Nobel award in Physics is in recognition of two landmark experiments in elementary particle physics. One provided the confirmation of the neutrino, as envisaged by Pauli more than two decades earlier. The second discovered the heavy charged lepton τ which heralded the third, and perhaps the last, generation of the ultimate constituents of matter to which the top and bottom belong. A summary of the discoveries made in the world of leptons is given in the table below. The third generation has now started getting Nobel prizes. It should be noted that ν_τ still needs to be identified experimentally (and hence the question marks in the last row of the table). For this one has to demonstrate that τ's are produced directly in collisions of ν_τ with nuclear targets.

Generation	*Lepton*	*Discoverer(s (year))*	*Nobel Prize (year)*
1	electron *e*	J J Thomson (1897)	J J Thomson (1906)
	electron-neutrino ν_e	C L Cowan *et al* (1956)	F J Reines (1995)
2	muon μ	J C Street, E C Stevenson C D Anderson, S H Neddermeyer (1936)	-----
	muon-neutrino ν_μ	G Danby *et al* (1962)	M Schwartz, L M Lederman J Steinberger (1988)
3	tau τ	M L Perl *et al* (1975)	M L Perl (1995)
	tau-neutrino ν_τ	?	?

Martin Perl (Stanford University, Stanford), aged 68, assisted by a 35-member team, discovered the 'tau lepton' in 1975. This particle carries one unit of electric charge and weighs approximately twice as much as a proton. It has a very short life, of only a fraction of a picosecond (millionth of a millionth of a second). Thus tau has the distinction of being 'the heaviest' and 'the shortest-lived' lepton observed. It is interesting that while Reines's neutrino results were in some sense expected, Perl's tau discovery came as a complete surprise.

Brief History of the Neutrino

Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.

(John Updike)

The 'birth' of neutrino can be traced to a letter of 4 December 1930 written by Pauli from Zurich. He mentioned that he had hit upon the neutrino as a "desperate remedy" to save, among other things, the principle of energy conservation in beta decay. The particle was to possess no electric charge but carried the missing energy and momentum and escaped the detecting equipment. The famous beta decay theory of Fermi appeared in 1934, wherein Fermi named the Pauli particle 'the neutrino', meaning the little neutral one.

It is interesting that even the great Pauli did not fully recognize the implications of the neutrino, particularly in regard to its penetrating power. Initially he thought he had done a'frightful thing' as the neutrino was expected to have penetrating power similar to, or about 10 times larger than, a gamma ray. However in 1934 Hans Bethe and Rudolf Peierls argued that the neutrino had to be even more elusive as its interaction mean free path had to be astronomical in magnitude.

Detection of the Reactor Neutrino

The first neutrino reaction to be observed (as is customary, here we are using the word 'neutrino' in its generic sense although, strictly speaking, what Reines and his group detected were signals from the electron-antineutrino $\bar{\nu}_e$) was the reaction.

$$\bar{\nu}_e + p \longrightarrow e^+ + n$$

driven by the antineutrinos from the nuclear reactor. This reaction is essentially the reverse of the neutron decay

$$n \longrightarrow p + e^- + \bar{\nu}_e.$$

The underlying idea was to look for a pair of scintillator pulses; the first (prompt) pulse due to positron annihilation and the second (delayed) one due to capture of the 'moderated' neutron. The experiment was performed around 1955-56. Projectiles came from the reactor located at the Savannah River Plant, in South Carolina State, USA, and targets were the protons in a solution of water mixed with cadmium chloride (Cd is a good absorber of thermal neutrons). The experimental appara-

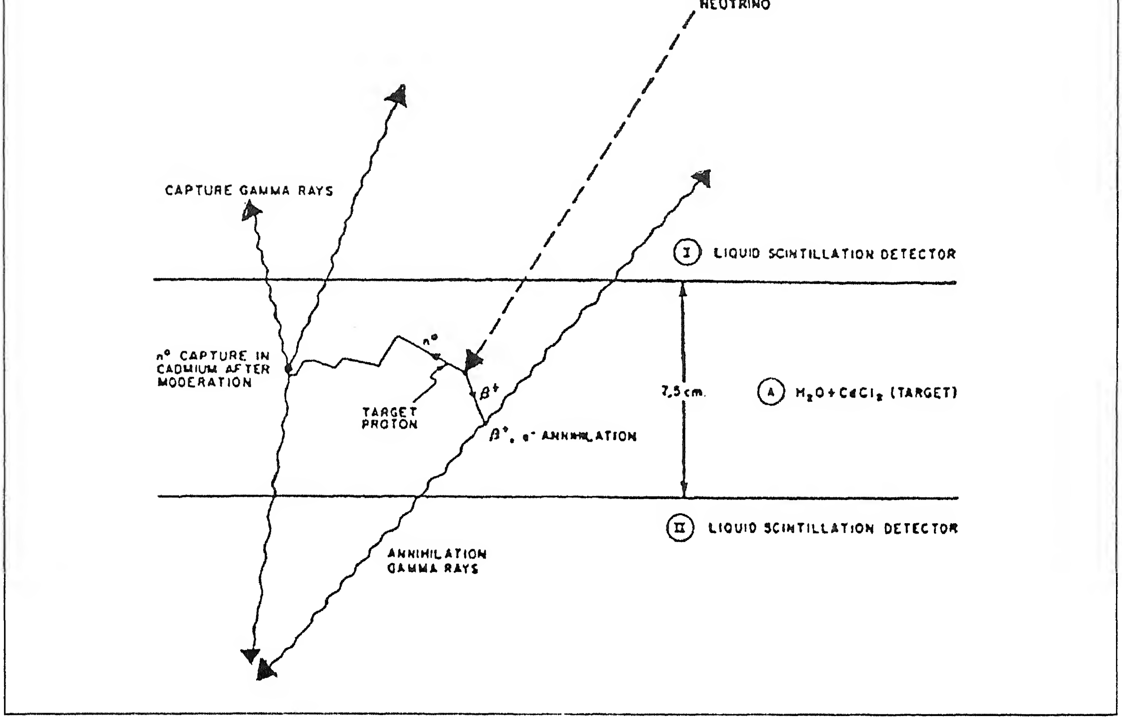


Figure 1 Schematic diagram of the neutrino detector of the Reines-Cowan experiment.

tus was a sandwich of target tanks (containing a solution of water and $CdCl_2$) and liquid scintillation detectors.

An event meant the detection of two prompt coincidences (see *Figure 1*): the first one was between the two photons (each having 0.511 MeV energy) of the positron annihilation, and the second coincidence was due to the capture of the neutron by cadmium giving a few photons. The second pulse occurred after several micro-seconds of the positron flash, because the neutron took that much time to degrade its energy to the level of thermal energies in the target water. The experiment involved, among other things, measuring energies of the pulses, their time-delays, etc. The observed signal did vary with the reactor power output, and hence with the neutrino flux. It gave an average rate of 2.88 ± 0.22 counts/hour, consistent with the value that is expected from the inverse beta reaction. In this way the neutrino was experimentally verified.

We know very little in regard to the electron-neutrino (and even less about other neutrinos). As for its rest mass, data on the end-point of the beta electron spectra only show that it cannot exceed a few eV. An important feature of ν_e is that it is *left-handed*: the spin of the neutrino, which has a magnitude of half a natural unit, is observed to be aligned *opposite* to the momentum direction. This intrinsic

property of the neutrino was discovered in 1958 in an exceedingly clever experiment performed by Goldhaber, Grodzins and Sunyar.

Experimental data using the ν_e's are not extensive because it is difficult to obtain ν_e beams. The sun is a good source of ν_e but the solar neutrino fluxes are not well understood and constitute one of the challenging problems of current research. Recently the first experiment using a man-made source of pure ν_e was performed. It made use of an intense source of reactor-produced ^{51}Cr (which emits ν_e by electron capture) to calibrate the GALLEX solar neutrino detector located in Italy.

Discovery of the Tau Lepton

Tau is a heavier electron. It entered the scene unexpectedly in 1975. While the results of Reines needed the construction of power reactors, the discovery of the tau lepton needed high energy electron-positron colliders. Tau lepton is the third kind of charged lepton that exists in nature, the other two being the electron and the muon. (The Greek letter τ is the first in the word triton, meaning third).

The experiment was performed at the electron-positron collider called SPEAR (Stanford Positron Electron Accelerator Ring), where beams of e^- and e^+ were accelerated simultaneously in opposite directions in a ring and made to intersect. As the total center-of-mass energy (the sum of beam energies)

$$E_{cm} = E_{e-} + E_{e+} = 2E_{e-},$$

was tunable in the range 3-8 GeV, a pair of charged particles each having a rest mass of about 2 GeV could easily be produced at SPEAR.

Anomalous Events: The 'anomalous' events reported by Perl and collaborators corresponded to the following reactions

$$e^- + e^+ \longrightarrow e^- + \mu^+ + \text{i.p.},$$

$$\longrightarrow e^+ + \mu^- + \text{i.p.},$$

where 'i.p.' denotes invisible particles which left no trace in the detector. The ingenuity of the experimenters consisted in establishing that the oppositely-charged $e\mu$ pair was the result of separate decays of two new particles which were oppositely-charged and short-lived. At the energy $E_{cm} = 4.8$GeV there were 24 events (13 $e^+\mu^-$ and 11 $e^-\mu^+$).

The occurrence of anomalous events as a function of E_{cm} exhibited an increase around 4 GeV, indicating a threshold for producing them. The events were interpreted as proceeding from the reaction

$$e^+ + e^- \longrightarrow \tau^+ + \tau^-,$$

where the taus decayed immediately into lighter leptons. A new conservation law called the 'tau-lepton number' conservation is assumed. According to this, in the τ^- decay, a neutrino called the tau-neutrino (ν_τ) is always emitted; in the τ^+ decay a tau-antineutrino ($\bar{\nu}_\tau$) is emitted. Thus the anomalous event with, say, $e^-\mu^+$ was the result of decays

$$\tau^- \longrightarrow e^- + \bar{\nu}_e + \nu_\tau$$
$$\tau^+ \longrightarrow \mu^+ + \nu_\mu + \bar{\nu}_\tau$$

wherein the two neutrinos and the two anti-

1995 Nobel Laureates in Physics

Frederick Reines Martin L Perl

neutrinos constitute the invisible particles denoted earlier by 'i.p'.

Data gathered over the years support the view that the earlier e-μ universality, i.e. the similarity in the properties of the e and μ, can be extended to e-μ–τ universality. The earlier enigma regarding the existence of muon is thus deepened. It now becomes the so-called 'generation puzzle': among the ultimate constituents of matter, why do members of one generation behave exactly in the same way, except for the mass, as the corresponding members of another generation?

As for the tau mass, recent measurements at the Beijing Electron Positron Collider (BEPC) in China, give m_τ = 1777 MeV, with an error which is less than 1 MeV. The relatively large mass of tau implies that many final states are accessible for the tau decay. The availability of several possible channels for decay makes the tau a very shortlived particle. Its mean life is presently known to be about

$$\tau_\tau = 3 \times 10^{-13}\ \mathrm{s},$$

with 1% accuracy, to be compared with

$$\tau_\mu = 2.197 \times 10^{-06}\ \mathrm{s}.$$

Suggested Reading

C L Cowan Jr., F Reines, F B Harrison, J W Kruse, A D McGuire. *Science*, 124:103-104. 1956.

F Reines, and C L Cowan Jr. *Physics Today*, 10:12-18. August 1957.

M Goldhaber, L Grodzins and A W Sunyar. *Phys. Rev.* 105:1015-1017. 1958.

M L Perl, et al. *Phys. Rev. Lett.* 35: 1489-1492. 1975.

K V L Sarma is at Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400005, India.

Bose-Einstein Condensation Observed

High-Tech Experiment Confirms Long-Standing Prediction

Rajaram Nityananda

Statistics is concerned with the laws which govern large collections of random events. Statistical ideas entered physics through the work by Maxwell and Boltzmann on the kinetic theory of gases, more than a century ago. For example, they predicted that the probability distribution of one component of the velocity would be the bell shaped curve in *Figure 1. Figures 1 a,b* shows how the spread in velocity, (or momentum) of particles, decreases as the temperature is lowered.

In 1924, Satyendra Nath Bose, then in Dacca University, discovered a new form of statistics, which applies to indistinguishable par-

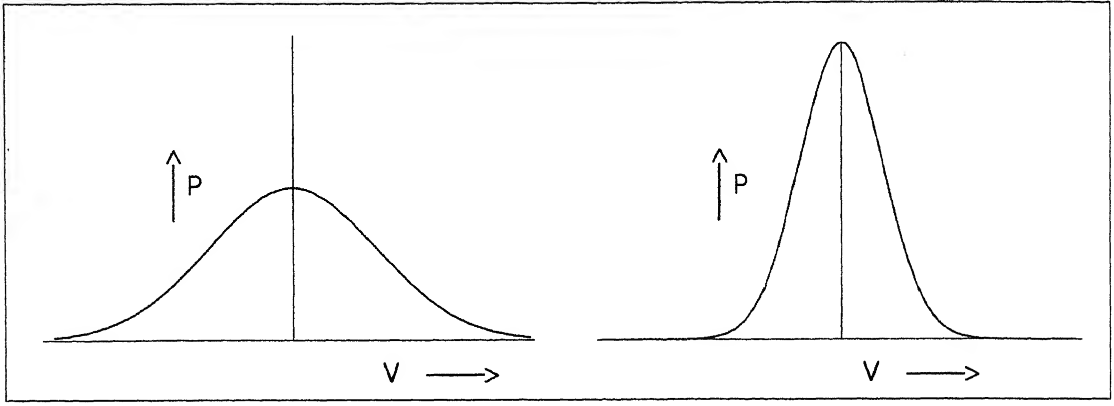
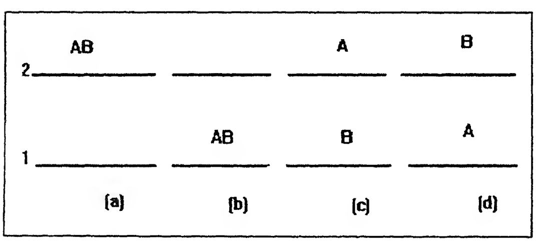


Figure 1 Probability distribution P(v) for molecules to have a velocity V along a given direction. (a) at a higher temperature (b) at a lower temperature. The graphs show the Maxwell-Boltzmann distribution.

ticles. To appreciate the new feature of his statistics, consider a situation in which two particles A and B are to be placed in either of two distinct *quantum* states 1 and 2. Boltzmann statistics recognizes four possibilities, which are shown in *Figures 2 a to d.*

According to Bose, the last two possibilities, (c) and (d), should be counted only as one, because the particles are indistinguishable. Notice that this modification increases the probability of the two cases (a) and (b), in which two particles occupy the same state, in

Figure 2 Four possible ways (a) to (d) of distributing two distinguishable particles A&B between two quantum state 1 and 2. (c) & (d) are the same where A&B are indistinguishable.



comparison to the case where they occupy different states. Bosons — particles obeying Bose statistics — are thus said to exhibit *bunching* or a *preference for being in the same state*. The concept of discrete states, which comes from quantum theory, is essential to this argument.

Bose's historic paper (see page 114) applied these ideas to the radiation emitted by a black body *i.e.*, photons. Einstein translated this paper into German for publication, hailed it as a great achievement, and took one more daring step forward. He applied the same counting rule to a gas like helium. His calculation showed that as the gas is cooled, the shape of the momentum distribution becomes more sharply peaked than the Boltzmann case (see *Figure 3a*). But even more important, below a special value of the temperature, a qualitatively new feature appears. A finite fraction of the total number of particles occupy the lowest energy state. This is shown as the spike in the

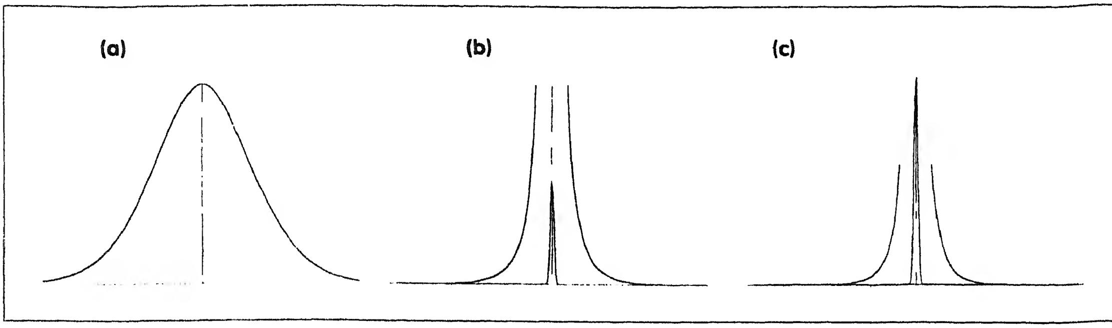


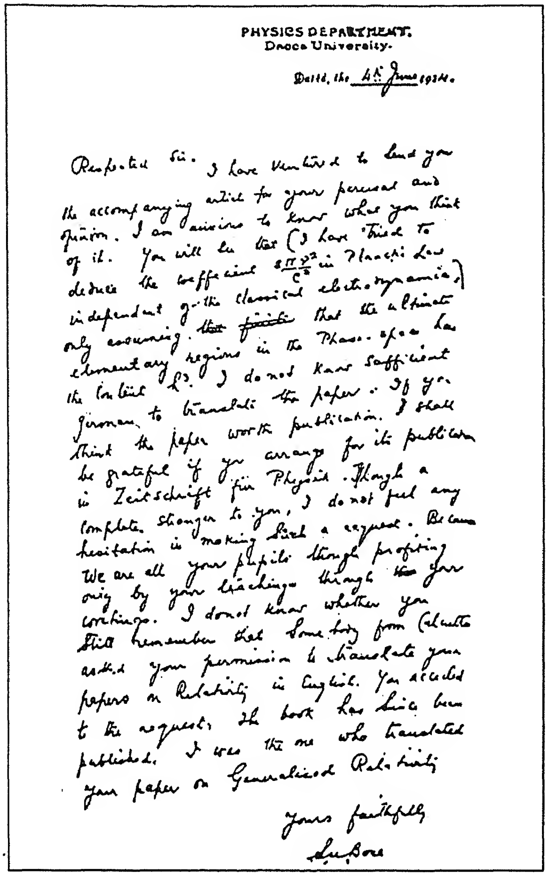
Figure 3 Velocity probability distribution according to Bose-Einstein statistics, with temperature lowered as one goes from (a) to (b) to (c). Note the slight difference in the shape of the curve in (a) as compared to Fig 1a. At the lowest temperature (c), a fraction of the molecules condense into a 'spike' at zero momentum.

probability distribution. (*Figure 3c*)

This fraction increases as one goes to lower temperatures. It is important to note that this *condensation* is in momentum space, unlike the usual condensation of a gas to a liquid, which occurs in position space. The other important feature is that this condensation is purely because of quantum statistics. There need be no attractive force between the particles.

Liquid helium shows remarkable behaviour at low temperatures. It is strongly believed that this is due to occupation of the zero momentum state. But the picture is complicated by the strong forces between neighbouring atoms in the liquid. Thus, one could say that the original prediction of Bose-Einstein condensation was not experimentally realised. This situation has now changed with the recent experiments at Boulder, in the USA, by a team of scientists working with the vapour of rubidium, an alkali metal. The isotope of rubidium used has integer total angular momentum, like helium (for which it is zero) and hence obeys Bose statistics. The reference to the original paper is given at the end of this article.

The density of atoms in the Boulder experiment was only about 10^{12} per cubic centimetre — far lower by a factor of 10^{11} than in normal matter. Thus the separation of neighbouring atoms was about 10^{-4} cm. To get a significant probability of two atoms in the same quantum state, it is necessary for the de Broglie wavelength to become larger than this separation. This wavelength, characteristic of quantum behaviour, is inversely proportional to the momentum which should therefore be very small. Since the rubidium atom is quite massive, this requires a very low velocity — less than one centimetre per second! The corresponding temperature is about 170 nanokelvin (1.7×10^{-7} °K!). The two remarkable technical feats involved are (a) reducing the kinetic energy of the atoms to such a low value, (b) keeping the 2000 atoms confined to a space of



PHYSICS DEPARTMENT.
Dacca University.
Dated, the 4th June 1924.

Respected Sir, I have ventured to send you the accompanying article for your perusal and opinion. I am anxious to know what you think of it. You will see that I have tried to deduce the coefficient $\frac{8\pi\nu^2}{c^3}$ in Planck's Law independent of the classical electrodynamics, only assuming that the ultimate elementary regions in the Phase-space has the content h^3. I do not know sufficient German to translate the paper. If you think the paper worth publication I shall be grateful if you arrange for its publication in Zeitschrift für Physik. Though a complete stranger to you, I do not feel any hesitation in making such a request. Because we are all your pupils though profiting only by your teachings through your writings. I do not know whether you still remember that somebody from Calcutta asked your permission to translate your papers on Relativity in English. You acceded to the request. The book has since been published. I was the one who translated your paper on Generalised Relativity.

Yours faithfully
S N Bose

size about 10^{-3}cm, without material walls (which would of course heat the atoms).

The first stage of cooling is achieved with a set of laser beams, propagating in different directions. (This seems strange since we usually think of such beams as a source of heat!). Their frequencies are tuned to just below the natural (resonant) frequency of the atom. As an atom moves in any direction, the Doppler effect shifts the frequency of an oppositely directed beam upwards so that it has a greater probability of colliding with the atom and slowing it down. The next stage of cooling is by evaporation — as in the humble mud pot!. The trap for the atoms uses specially designed magnetic fields, as well as careful control of the magnetic moments of the atoms to keep them antiparallel to the field. Under these conditions, atoms are repelled from the strong field regions, which act as walls. The magnetic field is also used cleverly to control evaporation.

All these techniques were of course perfected by many researchers working for several years, before being used in the final demonstration of Bose-Einstein condensation. To measure the momenta of the particles, the trapping magnetic fields were reduced so that the atoms expanded freely, moving a distance proportional to their velocity. The spatial distribution of the atoms was measured by casting a shadow with (yet!) another laser beam. The measured momentum distribution showed the spike characteristic of the lowest energy state in the trap. Apart from being a striking illustration of basic physical principles, the condensation will undoubtedly find uses in precision measurements, and in exploring new regimes in the behaviour of interacting atoms at low temperatures. There is poetic justice in the use of lasers, which depend on the statistics proposed by Bose for radiation, to finally verify and demonstrate Einstein's brilliant extension of Bose's work to atoms.

Suggested Reading

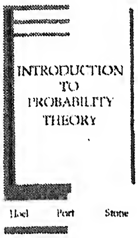
W H Anderson, J R Ensher, M R Matthews, C E Wieman, and E A Cornell. ***Science*****. 269: 198 1995.**

Rajaram Nityananda is with Raman Research Institute, Bangalore 560080.

Probability Theory Without Tears!

Not Too Austere, Not Too Chatty

S Ramasubramanian



Introduction to Probability Theory
P G Hoel, S C Port, and C J Stone
Universal Book Stall, New Delhi. 1995
pp. 258. Rs. 75.

The book assumes only a knowledge of calculus (including multiple integration); no knowledge of measure theory or linear algebra is assumed.

William Feller, in the preface to the third edition of his classic, observes that even in the 1940's few mathematicians recognised probability as a legitimate branch of mathematics and that applications were limited in scope. Today, however, as the opening paragraph of the book under review says, "probability theory is the branch of mathematics that is concerned with random (or chance) phenomena; it has attracted people to its study both because of its intrinsic interest and its successful applications to many areas within the physical, biological and social sciences, in engineering, and in the business world". A beginner to the subject is, therefore, likely to be interested not merely in the mathematical nuances but also in the applications (especially in statistics), and may want to acquire a reasonable working knowledge of the jargon, assumptions, limitations, etc.; in other words, he or she may be interested in understanding what probability theory is about and what it is not about. (It may interest the reader to note two of the extreme views about probability: the uninitiated very often consider probability theory to be a bag of tricks to solve combinatorial problems, and the professional mathematician at times dismisses it as a branch of measure theory. Needless to say these points of view reflect only two facets of the subject and are far from a complete picture.) Because of the relatively short history of probability theory as a "legitimate" branch of mathematics, a beginner may be misled by obscure, inelegant or even inaccurate presentations of important concepts. (One often wonders if the issue of "legitimacy" has anything to do with gambling dens where probability theory had its humble beginnings.) Also, she or he may be put off by the mathematical hairsplitting of advanced treatises. A good book intended for beginners should avoid these pitfalls. Too austere an approach will make one interested in a working knowledge of the subject uncomfortable, whereas too chatty a style will drive away a mathematically inclined student.

In this context it is very satisfying to note that the highly successful text book by Hoel, Port and Stone is now available to Indian students at an affordable price. The book assumes only a knowledge of calculus (including multiple integration); no knowledge of measure theory or linear algebra is assumed. After quickly going through some very interesting combi-

natorial problems, the book deals with basic notions concerning discrete and (absolutely) continuous random variables, expectations, moments, standard distributions, transformations of random variables, characteristic functions, central limit theorem and applications. A short chapter on random walks and Poisson processes is added at the end to serve as a brief encounter with stochastic processes. In other words, the book is ideally suited for a one-semester course on "non-measure theoretic" probability at the III B.Sc./ I M.Sc. level.

A highlight of the book is that a proof of the central limit theorem is presented assuming inversion and continuity theorems for characteristic functions; this should whet the appetite of a mathematically inclined student. Another salient feature is that the sampling distributions of statistics are derived. Concepts are explained clearly and proofs are given whenever possible using only calculus. When proofs are not presented, what is being assumed and what needs to be proved are stated carefully. Examples and exercises have been chosen with care; exercises are designed to test the understanding and build the confidence of the student. Perhaps the greatest merit of the book is that it can be used even by a (diligent) student of average ability as self-study material.

The reviewer, however, would like to make the following comments. There could have been more non-routine exercises to provoke an above-average student. It could have been mentioned that characteristic functions are also called Fourier transforms (and Fourier series in the case of integer valued random variables). Some comments could have been made concerning the need to have the concept of σ-field; (that is, why it is not suitable to have the power set of the sample space as the set of events); this could have been done in the chapter on continuous random variables and references to advanced texts on measure theory cited. (Of course, to be fair to the authors it must be said that σ-field remains an enigma in most elementary texts.)

To sum up, the book will serve as an excellent preparation (without tears) for a course in statistics or further study in probability theory and stochastic processes. It will enable the reader to build up enough confidence to take on more advanced texts like the ones by Billingsley, Feller, Parthasarathy, and Rao.

Suggested Reading

P Billingsley. Probability and Measure . (Second Edition), John Wiley. 1994.

W Feller. An Introduction to Probability Theory and Its Applications . Vol. 1. (Third Edition). Wiley-Eastern, New Delhi. 1993.

W Feller. An Introduction to Probability Theory and Its Applications , Vol. 2. Wiley-Eastern, New Delhi. 1984.

K R Parthasarathy. Introduction to Probability and Measure. Macmillan Co. of India. New Delhi. 1977.

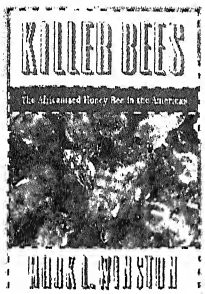
C R Rao. Linear Statistical Inference and its Applications . (Second Edition). Wiley-Eastern, New Delhi. 1984.

S Ramasubramanian is with the Statistics and Mathematics Unit, Indian Statistical Institute, 8th Mile, Mysore Road, R V College Post, Bangalore 560 059.

Africans in the Americas: A Problem?

A Cool Objective Assessment of the Killer Bee Problem

Raghavendra Gadagkar



Killer Bees- The Africanized Honey Bee in the Americas
Mark L Winston
Harvard University Press, Cambridge, Massachusetts, 1992.
pp. xiii + 162, $10.95.

In the last issue of ***Resonance***, you read about the honeybee dance language and how the construction of a robot bee helped clear some of the uncertainties regarding the efficacy of the dance language. Perhaps, in a future issue of ***Resonance***, we will feature the honey bee as a member of an exemplary animal society.

There is an undeniable negative side to honey bees for, not only do they yield honey, they also sting! Looked at dispassionately from the point of view of an evolutionary biologist, the sting of the bee is a marvel of nature. What about the less dispassionate point of view of the victim? Bee stings are mildly painful and one or two occasional stings do no great harm unless you are hypersensitive, which is a rather rare condition. Bee keepers receive hundreds of stings and are apparently none the worse for it.

What about the *killer bee*? Many readers may have heard that a killer bee is spreading across

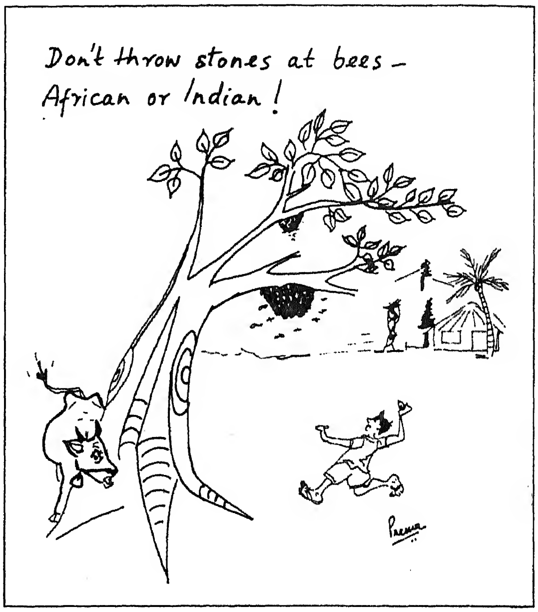
> Winston writes : "Merely walking toward the colonies elicited a massive response on the part of the bees, so that the situation was out of control before we smoked and opened our first colony".

South America and has now arrived in North America, killing hundreds of people and cattle and destroying local apiculture on its way. I once saw a rather stupid movie called *The Swarm* in which giant killer bees invaded the United States and destroyed anything coming their way including nuclear missiles! There has been so much media hype on the killer bee that it is high time we had a cool, objective assessment of the killer bee problem. Mark Winston has done just that in the book under review.

There are many virtues of this book. First it does not hesitate to tell the truth. Killer bees or *Africanized* bees as Winston prefers to call them, are real. They have been spreading across South and Central America at a speed of 300 to 500 kilometres a year, reaching densities of 6 colonies per square kilometre. It is estimated that today there are at least one trillion (that's 10^{12}!) Africanized bees, making up 50 to 200 million colonies in Latin America. Nor does Winston suppress their ferociousness. Let me quote him. "Merely walking toward the colonies elicited a massive

> The Africanized bee is very successful as a wild or feral bee and makes a poor candidate for managed bee keeping.

response on the part of the bees, so that the situation was out of control before we smoked and opened our first colony. Bees were everywhere, stinging through our layered clothing and banging into our veils and helmets with such ferocity that we could barely hear each other. It was a hot, humid day, and the combination of sweat, noise, and stings forced us to retreat after examining only a few colonies. The bees followed us all the way back to the car, and we had to keep our equipment on until we were far out of their stinging range. As we drove off, we could see the farmers swatting at the bees and two of their cows were being stung; we had to stop and move the animals farther away to safety." Writing even more candidly about the situation in the United States, Winston writes "Our response to the Africanized bee entered a new phase on 15 October 1990, when a colony of the bees was found ... near ... Texas ... The first stinging incident occurred ... in May 1991 ... the southeast corner of Texas is under quarantine ... the governor ... approved an emergency appropriation of $187,000,. ... to .... assist bee keepers." An equally important virtue of this book is the extraordinary clarity with which Winston is able to relate the ecology and behaviour of the Africanized bee to its success as a killer bee. Of course I will not reveal all the details but the net result is that the Africanized bee is very successful as a wild or feral bee and makes a poor candidate for managed bee keeping. Yet another virtue of this book is the large number of realistic strategies suggested for coping with the Africanized bees. To learn about these, read the book!



How did the problem of the killer bee begin in the first place? Honey bees are not native to the Americas; the European bee *Apis mellifera* had been introduced there for bee keeping but is not good for this purpose in tropical regions. The Brazilian government therefore asked one of their geneticists, Warwick Kerr, to import and breed bees better suited to that country. As Winston says, "for stock he (Warwick Kerr) naturally looked to Africa, the original habitat of tropical honey bees ... The Kerr group knew that the African bees had a reputation for being highly aggressive, but reasoned that they could cross African with European bees to produce a hybrid with

As luck would have it, the natural crossing of African bees with the local Brazilian bees did not yield the mild but industrious hybrids that Kerr had expected.

the gentle European characteristics, but the supposedly high honey production, of the African bees." Unfortunately some of the imported African queens escaped and some were deliberately distributed to bee keepers before proper breeding and testing. As luck would have it, the natural crossing of African bees with the local Brazilian bees did not yield the mild but industrious hybrids that Kerr had expected. It is said that a particularly beautiful woman once proposed marriage to Bernard Shaw with the tempting words "imagine, our children with my beauty and your brains!". Shaw is said to have replied, "yes my dear, but what if they have my beauty and your brains?" Something similar probably happened in the case of the African-European hybrid honey bees.

> This book explains how to deal rationally with a biological enemy and a superb illustration of how biological and ecological research can truly contribute to management of a pest.

Mark Winston is eminently qualified to write about the Africanized bees. I quote just enough to whet your appetite. He writes : "In the fall of 1975 I arrived at the University of Kansas to pursue a doctorate in entomology ... My supervisor ... had just received a federal grant to study ... the Africanized honey bee ... The first team in French Guiana consisted of myself, Gard Otis, David Roubik, their wives and children, and of course our leader, Chip Taylor - who periodically came down with fresh T-shirts, mail, equipment, and lots of advice and enthusiasm."

The Africanized honey bee is unlikely ever to be a problem in India. Why then do I recommend Winston's book to students in India? Because this book is not about narrow solutions to a narrow problem. It is a model on how to deal rationally with a biological enemy and a superb illustration of how biological and ecological research can truly contribute to management of a pest. Above all the book brings out vividly Winston's love for biology: "When all the action programmes, controversies, and dilemmas caused by the Africanized bees have receded into the past, we will be left with a natural history paradigm that can only contribute to our appreciation of the biological world."

Raghavendra Gadagkar is with the Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560012 and Jawaharlal Nehru Centre for Advanced Scientific Research, Jakkur, Bangalore 560064.

Papin's description of his pressure cooker (1681) ... A New Digester or Engine for Softening Bones, containing the Description of its Make and Use of these Particulars, Viz. Cookery, Voyages at Sea, Confectionary, Making of Drinks, Chymistry and Dyeing, with an account of the Price a good big Engine will cost and of the Profit it will afford.

Books Received

Numerical Methods with Programs in Basic, Fortran and Pascal
S Balachandra Rao, C K Shantha
Universities Press India Ltd.
Orient Longman Ltd.
1992, Rs.120.

Programming Techniques for Personal Computers
Kamesh Govindaraju
BPB Publications.
BPB Book Centre.
1995, Rs.66.

Computer Related Mathematics
Brain A S Patterson
BPB Publications.
BPB Book Centre
1992, Rs.99.

'O' Level Made Simple. Module 1: Computer Fundamentals
Satish Jain
BPB Publications.
BPB Book Centre.
1994, Rs.99.

Computer Programming in C
V Rajaraman
Prentice Hall (India) P. Ltd.
1994, Rs.110.

Natural Language Processing. A Paninian Perspective
A Bharati, V Chaitanya, R Sangal
Prentice Hall (India) P. Ltd.
1995, Rs.95.

Expert Systems
Jean Louis Ermine
Prentice Hall (India) P. Ltd.
1995, Rs.75.

Wave Optics and its Applications
Rajpal S Sirodhi
Universities Press India Ltd.
Orient Longman Ltd.
1993, Rs.205.

Introduction to System Dynamics Modelling
Pratap K J Mohapatra, Purnendu Mandal, Madhab C Bora
Universities Press India Ltd.
Orient Longman Ltd.
1994, Rs.180.

Innovative Science Teaching for Physical Science Teachers
Radha Mohan
Prentice Hall (India) P. Ltd.
1995, Rs.150.

Elements of Biotechnology
P K Gupta
Rastogi & Co.
1995, Rs.130.

Cytogenetics
P K Gupta
Rastogi & Co.
1995, Rs.225.

Genetics
P K Gupta
Rastogi & Co.
1994, Rs.160.

Introductory Biochemistry
S K Singla, O P Chauhan
Kalyani Publishers
1995, Rs.75.

Space Today
M Sundara Rajan
National Book Trust, India.
1987, Rs.74.

Integrated Ph.D Programme in Biological, Chemical and Physical Sciences at Indian Institute of Science

Genesis

The integrated Ph.D Programme in Biological, Chemical and Physical Sciences was born out of the recommendations of the Forward Planning Committee of the Institute which examined the future of scientific research and education at the Institute of Science. It was felt that in spite of the major drainoff from science that takes place at the +2 stage, there still exists a large pool of bright, interested students at the B.Sc. level from which a few can be drawn into an Integrated Ph.D. programme in the sciences with the prospect of Ph.D. graduation within a period of 5-6 years. The Integrated Ph.D. programme in Chemical Sciences was started in the academic year 1990-91, followed by Physical Sciences in the year 1991-92 and Biological Sciences in the year 1992-93.

Introduction

The programme represents a novel attempt at training and developing high quality professional scientists in India. The basic idea is to induct a small number of talented, strongly motivated young students at the B.Sc. level and impart to them sound, well-balanced science training (biology, chemistry and physics) in an atmosphere of contemporary, active research.

About the Programme

The Institute now offers the Integrated Ph.D. Programme in Biological, Chemical and Physical Sciences for candidates with first class B.Sc. degree who have a flair and aptitude to pursue research in any one of these programmes. The programme consists of flexible course work with emphasis on research-oriented laboratory projects to impart training in laboratory skills and techniques, followed by advanced research with special emphasis on an interdisciplinary approach. The course work is carefully designed to provide basic education in any one of the branches of science (biology, chemistry, physics) and the formal training needed for quality professional

research; it also provides wide scope for self-learning. The laboratory programme is of an internship-type where there are ample opportunities to learn and avail of personal training in all aspects of advanced laboratory techniques. Students are expected to take advantage of the computer network of the Institute including Internet to access the world of scientific knowledge. The programme includes tutorial classes, problem solving sessions, faculty advisory system and a multitude of avenues for carrying out research in various science disciplines. All candidates admitted to the programme are awarded an interim MS degree at the end of three years after successful completion of course work and the comprehensive examination. The students are qualified to appear for the UGC/CSIR/NET after successful completion of the course work and project. The admission procedures, graduation requirements and other details about the programme are given below.

- *Biological Sciences*

Participating Departments/Centres: Biochemistry, Ecological Sciences, Genetic Engineering, Reproductive Biology & Molecular Endocrinology, Developmental Biology & Genetics, Molecular Biophysics, and Microbiology & Cell Biology.

Areas of Research: Biomembranes - physical and physiological studies; structure-function of nucleic acids; gene structure and function in prokaryotes and eukaryotes; microbial genetics; sex determination; recombinant DNA technology; molecular virology and mechanisms of disease processes; enzymology, protein chemistry and engineering; cellular and applied immunology; molecular endocrinology and reproductive biology; conformation of biomolecules and biopolymers; protein and virus crystallography; structural and computational biology; mathematical ecology; human ecology; behaviour and sociobiology; conservation ecology; plant molecular biology and development.

Eligibility: First class (as declared by the university) B.Sc. in physical, chemical or biological sciences (including pharmaceutical, veterinary and agricultural sciences) with chemistry as one of the subjects at the B.Sc. level, and mathematics or physics at the PUC/ plus 2 level.

- *Chemical Sciences*

Participating Departments: Organic Chemistry, Inorganic & Physical Chemistry, Solid State & Structural Chemistry and Materials Research Centre.

Areas of Research: Ultrafast chemical dynamics; theoretical chemistry; surface chemistry and catalysis; solid state chemistry; amorphous materials; ceramics, thin films; chemistry of super-conductors; synthetic organic chemistry; physical organic chemistry; biomimetic chemistry and bio-organic chemistry; organometallic chemistry; chemistry of transition & non-transition metals; chemistry of polymers.

Eligibility: First class (as declared by the university) B.Sc. with chemistry as one of the main subjects, and mathematics at the PUC/plus 2 level.

- *Physical Sciences*

Participating Department: Physics

Areas of Research: Physics of disordered systems; high-temperature superconductivity; strongly correlated electron systems; low-temperature physics; complex fluids; low dimensional conductors; quasicrystals; magnetic resonance; Raman spectroscopy; point contact and tunneling spectroscopies; structure and function of biomolecules; physics of semiconductors; phase transitions; dynamics of complex systems; plasma physics; solar, stellar and galactic astrophysics; quantum field theory; classical and quantum optics; computational physics.

Eligibility: First class (as declared by the university) B.Sc. with physics as a main subject.

Selection Procedure

The selection of candidates for admission is solely on the basis of their performance in the entrance test followed by an interview. The candidates selected based on their entrance test performance, appear for an interview at the Institute. The entrance test is held at 14 centres located in various parts of the country and the candidates have to answer any one paper of 3 hours duration. The advertisement for admission to this programme appears in all the major newspapers in February/March every year.

Entrance Test

Candidates have to choose an appropriate paper among the following for admission to the chosen Ph.D. programme (biological/chemical/physical sciences): 1. Biological Sciences; 2. Chemical Sciences; 3. Physical Sciences.

Each question paper consists of two parts (Part I & Part II). Part I carries 30 marks. The questions in Part I are of the objective type and cover general 'scientific aptitude' in physics, chemistry, mathematics and biology. Part I of the question paper is common to all the papers and is compulsory.

For admission to Integrated Ph.D	*Paper to be answered*
• Physical Sciences	Physical Sciences
• Chemical or Biological Sciences	Chemical Sciences or Biological Sciences or Physical Sciences

Part II carries 70 marks and contains problems and questions requiring short answers. Candidates are required to indicate their choice of the paper in the application form and the answer book. Changes are not permitted.

Financial Support

All the students admitted to the Integrated Ph.D Programme receive some financial support in the form of scholarship for the first two years. The students are eligible for scholarship of Rs.2500 per month from the beginning of the third year.

S Chandrasekaran is a Professor in the Department of Organic Chemistry, Indian Institute of Science and the Co-ordinator of the Institute's Integrated Ph.D. programme.

Introductory Summer School on Astronomy and Astrophysics

The Introductory School on Astronomy and Astrophysics, proposed to be held during May 29 - June 8, 1996, at Pune, is designed to introduce the students of physics, mathematics, electronics engineering and technology to the exciting fields of astronomy and astrophysics (A&A). No previous knowledge of A&A is necessary. although familiarity with the basic principles of mathematics and physics will be required.

How to apply

In plain paper, in the following format: 1. name; 2. sex; 3. date of birth; 4. address for communication; 5. qualifications (standard X onwards) with institution/year/subjects/class/grade/percentage of marks obtained; 6. short write-up giving motivation for applying for the school; 7. previous summer schools attended, if any; 8. names and addresses of two referees (these referees should be teachers/project guides, etc.); and 9. signature with date.

The applicants should request the above referees to send their confidential assessments/recommendations in separate envelopes. Applications and referee reports should reach the *Coordinator, Core Programmes, IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007,* [phone: (0212) 351414, fax: (0212) 350760] by March 14, 1996.

The selected candidates will be informed by April 15, 1996. They will be provided travel, board and lodging for the duration of the school.

The School will be funded by the Department of Science and Technology (DST), New Delhi, and hosted by Inter University Centre for Astronomy and Astrophysics (IUCAA) and National Centre for Radio Astrophysics (NCRA) of the Tata Institute of Fundamental Research, Pune.

It is expected that about 35 students will participate in this programme. The programme of the school will consist of lectures, covering fundamentals of A&A as well as recent developments in the field. In addition, participants will take part in individual projects under suitable guidance. The lecturers for the School will be drawn from the leading A&A centres in the country, so that the participants will get an exposure to the work being done in these fields. There is a possibility for a few motivated students to spend an additional week at IUCAA / NCRA after the school.

- *Eligibility:* Students completing their 1st year M.Sc., (physics/applied mathematics/astronomy/electronics) or 3rd year B.E.,/B.Tech. in 1996 can apply. Exceptionally bright and motivated students completing their B.Sc. (Physics) in 1996 may also apply.

Murray Gell-Mann's discovery ... As an undergraduate at Yale, I had managed to get high grades in science and math courses without always understanding the point of what I was learning. In most cases, it seemed, what was required was merely to regurgitate on examinations what one had been fed in class. My views changed when I attended one of the sessions of the Harvard-MIT theoretical seminar. I had thought of the seminar as some sort of glorified class. In fact, it was not a class at all, but a serious discussion group on subjects in theoretical physics, particularly the physics of atomic nuclei and elementary particles. Professors, post-docs, and graduate students from both institutions attended; one theorist would lecture and then there would be a general discussion of the topic he had presented. I was unable to appreciate such scientific activity properly because my way of thinking was still circumscribed by notions of classes and grades and pleasing the teacher. (from *The Quark and the Jaguar: Adventures in the Simple and the Complex.* 1994)

Guidelines for Authors

Resonance - *journal of science education* is primarily targeted to undergraduate students and teachers. The journal invites contributions in various branches of science and emphasizes a lucid style that will attract readers from diverse backgrounds. A helpful general rule is that at least the first one third of the article should be readily understood by a general audience.

Articles on topics in the undergraduate curriculum, especially those which students often consider difficult to understand, new classroom experiments, emerging techniques and ideas and innovative procedures for teaching specific concepts are particularly welcome. The submitted contributions should not have appeared elsewhere.

Manuscripts should be submitted in *duplicate* to any of the editors. Authors having access to a PC are encouraged to submit an ASCII version on a floppy diskette. If necessary the editors may edit the manuscript substantially in order to maintain uniformity of presentation and to enhance readability. Illustrations and other material if reproduced, must be properly credited; it is the author's responsibility to obtain permission of reproduction (copies of letters of permission should be sent). In case of difficulty, please contact the editors.

Title Authors are encouraged to provide a 4-7 word title and a 4-10 word sub-title. One of these should be a precise technical description of the contents of the article, while the other must attract the general readers' attention.

Author(s) The author's name and mailing address should be provided. A photograph and a brief (in less than 100 words) biographical sketch may be added. Inclusion of phone and fax numbers and e-mail address would help in expediting the processing of manuscripts.

Summary and Brief Provide a 2 to 4 sentence summary, and preferably a one sentence brief for the contents page.

Style and Contents Use simple English. Keep the sentences short. Break up the text into logical units, with readily understandable headings for each. Do not use multiple sub sections. Articles should generally be 1000-2000 words long.

Illustrations Use figures, charts and schemes liberally. A few colour illustrations may be useful. Try to use good quality computer generated images, with neatly labelled axes, clear labels, fonts and shades. Figure captions must be written with care and in some detail. Key features of the illustration may be pointed out in the caption.

Boxes Highlights, summaries, biographical and historical notes and margin notes presented at a level different from the main body of the text and which nevertheless enhance the interest of the main theme can be placed as boxed items. These would be printed in a different typeface. Such a boxed item should fit in a printed page and not exceed 250 words.

Suggested Reading Avoid technical references. If some citations are necessary, mention these as part of the text. A list of suggested readings may be included at the end.

Layout It is preferable to place all the boxes, illustrations and their captions after the main text of the article. The suggested location of the boxes and figures in the printed version may be marked in the text. In the printed version, the main text will occupy two-thirds of each page. The remaining large margin space will be used to highlight the contents of key paragraphs, for figure captions, or perhaps even for small figures. The space is to be used imaginatively to draw attention to the article. Although the editors will attempt to prepare these entries, authors are encouraged to make suitable suggestions and provide them as an annexure.

Book Reviews

The following types of books will be reviewed : (1) text books in subjects of interest to the journal; (2) general books in science brought to the attention of students/teachers; (3) well-known classics; (4) books on educational methods. Books reviewed should generally be affordable to students/teachers (price range Rs.50 to 300).

New books will get preference in review. A list of books received by the academy office will be circulated among the editors who will then decide which ones are to be listed and which to be reviewed.

Acknowledgements

Resonance gratefully acknowledges the help received from the following individuals and establishments:

Swarnalatha Chandran, Sanjeev Galande, Rohini Godbole, N Kumar, Geetha Lakshmanan, Gautam Nadig, D Narasimha, S Ramasubramanian, Jayant Rao, V Ravi, Joseph Samuel, Supurna Sinha, Cherian Varughese.

Our special thanks to Dr K N Raju, Director, National Aerospace Laboratories (NAL) for graciously agreeing to offer NAL facilities in the production of the journal; to Ayan Guha for creating the logo for the new "Reflections" department; and to Mr Dilip Kumar of ITI, Bangalore for permitting us to print his beautiful eclipse photographs on the cover page.

Erratum

Page 111 of *Resonance*, Vol. 1, No. 1 (1996)
The text "Richard Feynman ... shared the Nobel Prize in 1964..."
should read "Richard Feynman ... shared the Nobel Prize in 1965..."

Annual Subscription Rates

	Personal	Institutional
India	Rs 100	Rs 200
Third World Countries	US $ 25	US $ 50
Other Countries	US $ 50	US $ 100

Send your subscriptions by cheque, DD or MO in favour of "Indian Academy of Sciences" to Circulation Department, Indian Academy of Sciences, C V Raman Avenue, PB No. 8005, Bangalore 560 080, India.

Edited and published by V K Gaur for the Indian Academy of Sciences, Bangalore 560 080. Printed at Thomson Press (I) Ltd., Faridabad 121 007.

Satyendra Nath Bose (1894-1974), along with Megh Nad Saha, established modern theoretical physics in India. Born and educated in Calcutta, he had a brilliant academic career through school and university. His teachers at Presidency College included J C Bose and P C Ray. After four years as lecturer in Calcutta University, he moved in 1921 to Dhaka University, working there until 1945. He then returned to Calcutta University as Khaira Professor, and was later Vice-Chancellor of Visva-Bharati.

While teaching M.Sc. students at Dhaka, Bose felt dissatisfied with existing derivations of Planck's Radiation Law. Spurred by discussions with Saha, he developed a logically satisfactory derivation based entirely on Einstein's photon concept and what was later recognized to be his own "principle of indistinguishability" of photons. He sent his work to Einstein in June 1924. Einstein immediately grasped its significance, translated it into German, and arranged for its publication in the Zeitschrift fur physik. *This is how quantum statistics was born.*

Einstein applied Bose's method to give the theory of the ideal quantum gas, and predicted the phenomenon of Bose-Einstein condensation. (See the article by Rajaram Nityananda on page 111). Bose's work was an important step on the path to quantum mechanics. Bose-Einstein (BE) and Fermi-Dirac (FD) statistics are the two major expressions of indistinguishability of identical particles in quantum theory. Particles obeying BE statistics are called 'bosons' — examples are the photon, the pi meson, and the W and Z particles. Bose's name has become part and parcel of modern physics.

SATYENDRA NATH BOSE
1894-1974